

ASTRONOMY

February 1982

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Galileo's Orbiter at Io



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Note: See Meade Catalog for detailed specifications and standard-accessories listings of telescope models shown.

Model 1020: 1000mm f/10 Telephoto Lens. Attaches to any standard camera tripod. Shown with optional Meade Photo Tripod.

4" Schmidt-Cassegrain, Model 2040, with Equatorial Wedge and Field Tripod.





ASTRONOMY

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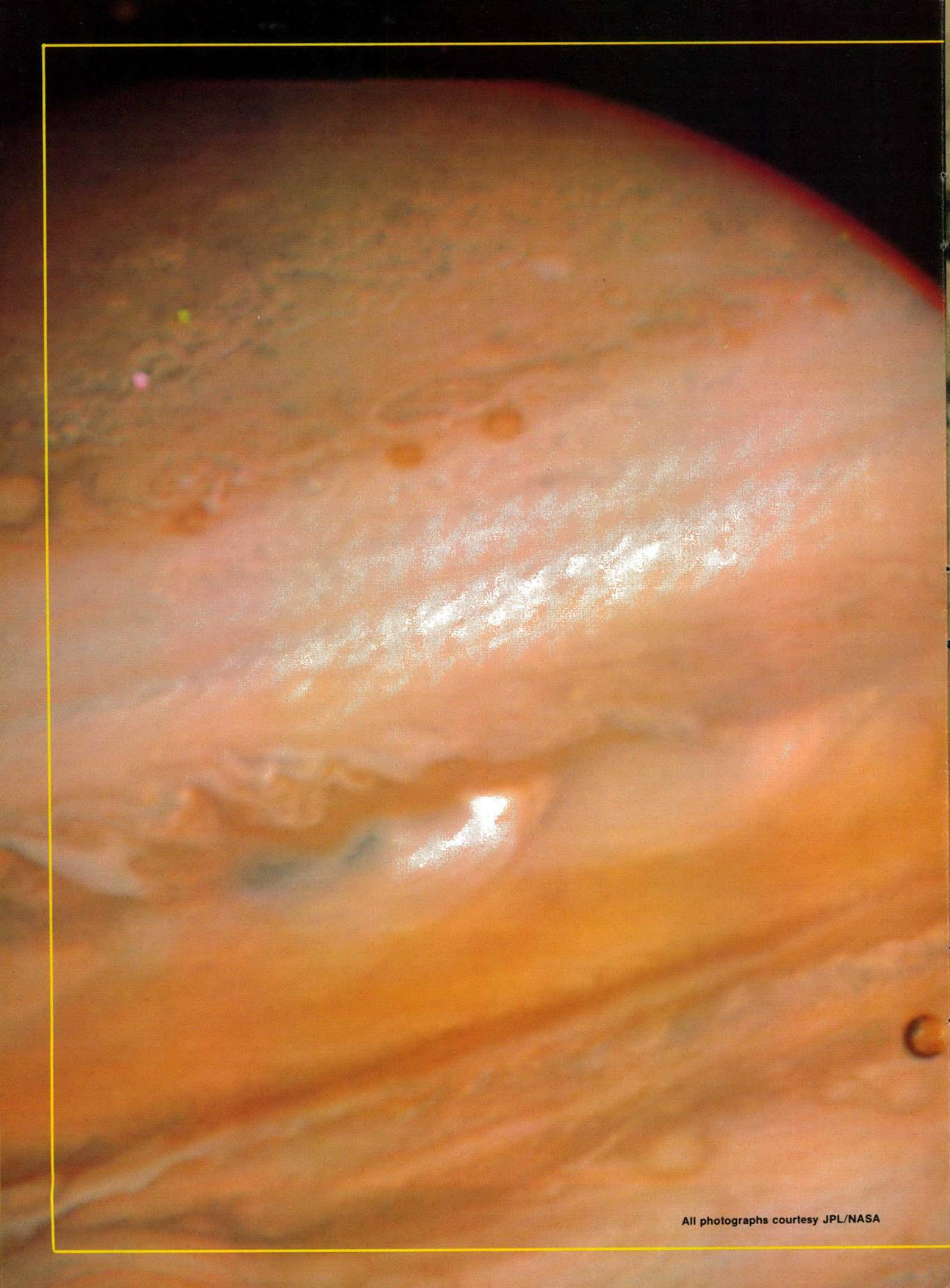
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Cover: This month, ASTRONOMY investigates the instruments, destinations, and objectives of the Galileo Mission to Jupiter — NASA's only remaining planetary effort — scheduled for launch in 1985. In this painting by Michael Carroll, the Galileo Orbiter — half of the probe/orbiter mission — samples the near-space environment of volcanically active Io. These pages: Jupiter's Great Red Spot — a storm more than 300 years old — dominates this image made by Voyager 1 in 1979. The Galileo Mission will directly sample Jupiter's atmosphere and expand our understanding of the gas giant — and the solar system — well beyond what we've learned from Voyager's flyby images. NASA/JPL photo.

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Galileo

Mission to Jupiter

by Clayne M. Yeates
and Theodore C. Clarke



On a spring day in April 1985, one of America's fleet of shuttle launch vehicles will thunder off its Cape Canaveral launch pad into Earth orbit. It will carry in its cargo bay the two components of the Galileo mission — an Orbiter and a Probe. Galileo will be mounted to the tip of a Centaur upper stage rocket that has been modified for launch from a shuttle.

Galileo, from Earth orbit, is bound for Jupiter.

Launch from Earth, even aboard a shuttle, is a punishing ordeal for a spacecraft. Powerful engine vibrations might damage delicate spacecraft parts, so Galileo has been stowed in "launch configuration." Its 15-foot diameter high-gain communications antenna lies folded forward like an umbrella, and two 16-foot booms carrying the nuclear power supplies — radioisotope thermoelectric generators — are snugged back, anchored securely against vibration. Part of the vital science payload, a boom carrying five of the 11 science experiments aboard the Orbiter, is also folded in. The Probe itself is safely tucked into the aft end of the spacecraft beneath the science scan platform which carries four more Orbiter science

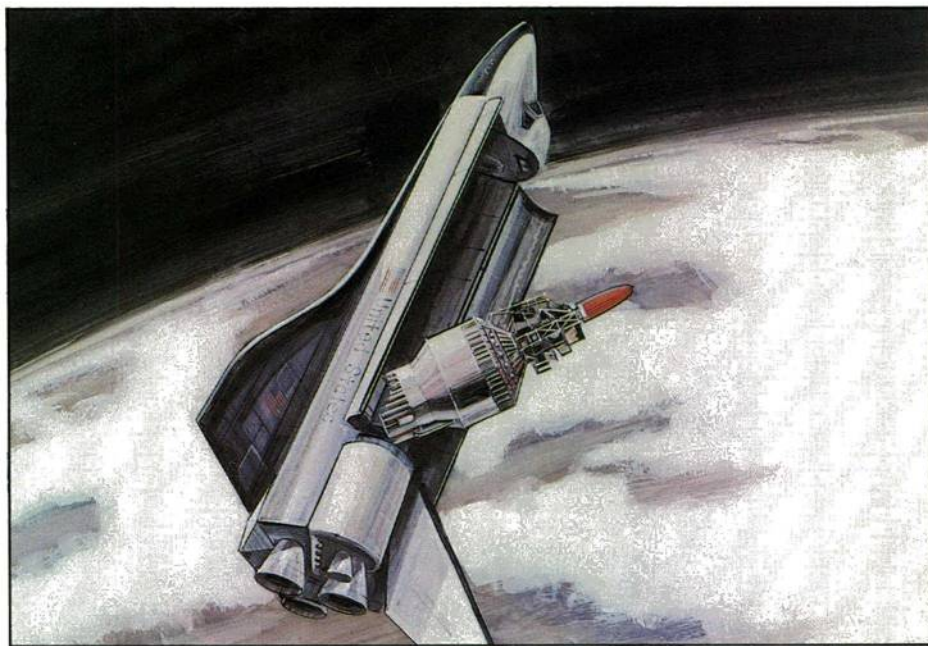
experiments.

Thirty minutes after orbit circularization, the shuttle's cargo bay doors open and expose Galileo to deep space for the first time. After the astronauts run an extensive engineering checkout of the spacecraft to confirm that it has survived launch, the tilt table holding Centaur-Galileo rotates 45 degrees. Pyrotechnic devices fire: a set of

steel springs gently shoves the combined 55,000 pound Centaur-Galileo away from the shuttle at one foot per second.

We wait. Nine minutes later, shuttle maneuvering system engines ignite and the hypersonic airplane-spacecraft peels off and moves silently and swiftly away from the Centaur-Galileo. Their busy day complete, the astronauts fly the shuttle back to Earth, touching down before the day is over on a sundrenched Florida landing strip.

For Galileo there is now no return. Six hours after lift off, forty-five minutes after separation from shuttle, at the end of its fourth Earth orbit, the Centaur main engines ignite and burn for 420 seconds. Galileo leaves Earth forever, bound for the



NASA/JPL

planet Jupiter.

The power supply and science booms will deploy, the Centaur rocket will separate and maneuver away from the spacecraft, and finally the umbrella-like high-gain antenna will open. Like a cosmic marionette, with its radio link to mission control acting as invisible strings, Galileo will begin its long coast away from the Sun on an elliptical trajectory to Jupiter.

History and Objectives

Plans for Galileo, then called the Jupiter Orbiter and Probe (JOP) mission, were already underway during 1975 at the Jet Propulsion Laboratory and Ames Research Center — more than two years before the launch of the Voyagers. The mission was part of a plan proposed by the Space Science Board of the National Academy of Science. Following the Voyager flyby reconnaissance, the highest priority NASA planetary objective was to be in-depth exploration of Jupiter.

Mission planners recognized as early as 1974 that the Galileo operation would require both an orbiter and an atmospheric entry probe in order to satisfy all three major exploration objectives:

- determination of the chemical composition and physical state of the jovian atmosphere
- investigation of the chemical composition and physical state of the jovian satellites
- investigation of the structure and physical dynamics of the jovian magnetosphere

These objectives are directly related to the major goals of the NASA planetary exploration program: to further our understanding of the origin and evolution of the solar system, the origin and evolution of life, and the Earth by comparative studies of the other planets.

Why is Jupiter so important? Why don't Mars, Venus, or Mercury rate additional study instead? Planetary scientists would like to investigate all the planets, but Jupiter rates highest — if there must be a choice — because it alone comes closest to satisfying the major goals of planetary exploration. Our theories of the origin of the solar system rest on the

assumption that all bodies formed from a gaseous material of uniform composition. As they cooled and contracted, the makeup of planets changed. The terrestrial planets lost most of the light elements as they evolved, but the larger planets kept them. Essential to exploring the history of the solar system, then, are measurements of elemental abundances — the chemical makeup of a variety of objects.

Jupiter, of all the planets, asteroids, comets, and satellites, holds a key. Its atmospheric composition could be representative of the primordial local solar nebular material. While other bodies evolved and lost material, especially hydrogen and helium, proto-Jupiter's great gravitational attraction held on to it. Because it retains this primordial composition, Jupiter is a better cosmological "laboratory" than any of the other planets.

The jovian system is also a solar system in miniature — massive gaseous Jupiter circled by a retinue of small, icy satellites. Each of the four major jovian satellites shows a different level of geological activity — and each has followed a different evolutionary path. A single spacecraft touring through the jovian system can investigate not only the most massive planet in the solar system, but also a wide range of small planetary bodies.



Jupiter also ranks high among the planets as a source of information on the origin and evolution of life in the universe. Its atmosphere is a nearly ideal chemical laboratory. Ingredients assumed to be present in the terrestrial atmosphere at the time life originated are all present. Provided that enough energy is available to drive chemical processes, and that the chemical balance is right, there is a strong possibility that complex organic molecules have formed — further clues in the search for origin of life.

En Route to Jupiter

During the cruise phase of the mission, Galileo will travel nearly one billion kilometers in just under two years. The antennas of the NASA-run Deep Space Network and the German tracking facility at Wilheim will follow the the spacecraft on its journey. NASA's antennas, located in California, Spain, and Australia will provide two 8-hour tracking periods per week,

and the German station will track Galileo for five 8-hour periods per week.

On the long flight outward, fields and particles experiments will be busy collecting data on solar magnetic fields and the charged particles of the solar wind that flow through interplanetary space past the spacecraft. Except for occasional calibrations, however, there is no planned "science activity" for the remote sensing instruments mounted on the scan platform.

Finally, as Jupiter looms larger, the pace of activity will step up. In preparation for separation of the Probe, small thrusters will fire, making the precise trajectory correction maneuvers to prepare for arrival at Jupiter.

Atmosphere Science

The preliminary reconnaissance of the jovian system by the Pioneer and Voyager spacecraft

Galileo's Orbiter and Probe Instruments

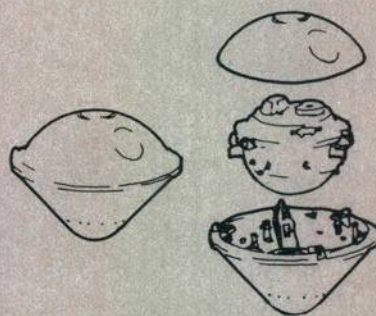
Orbiter Instruments

Eleven scientific instruments aboard the Orbiter will view Jupiter and its satellites for nearly two years.

- Near Infrared Mapping Spectrometer (NIMS) — will measure reflected sunlight and heat emission from Jupiter's atmosphere to study composition, cloud structure, and temperature profiles. It will also study the chemistry and mineralogy of the satellite surfaces.
- PhotoPolarimeter Radiometer (PPR) — will measure temperature profiles plus the energy balance of Jupiter's atmosphere, and the planet's cloud characteristics and composition. It will also measure the brightness, textures, and temperatures of the satellites.
- Solid State Imaging (SSI) Camera — will take pictures from which scientists will measure atmospheric motions, both horizontal velocity fields and vertical profiles of Jupiter, and the geology and morphology of the satellite surfaces.
- Ultraviolet Spectrometer (UVS) — will investigate the atmosphere of Jupiter above the cloudtops, explore and characterize the atmosphere of the satellites, and measure Io's torus.

In addition, five fields and particles instruments — the Plasma Science Instrument (PLS), the Energetic Particle Detector (EPD), the Plasma Wave Experiment (PWS), the Magnetometer (MAG), and the Dust Detector (DDS) will explore the magnetic and particle environment of Jupiter and its satellites.

Even the signals from the spacecraft radio will provide data. Their Doppler shifts will allow scientists to track Galileo precisely as it moves through the jovian and satellite gravity fields, yielding a detailed model of it. Scientists will deduce the mass distribution of the planet's interior from this model.



Probe Instruments

The Galileo Probe will plunge into Jupiter's atmosphere carrying six instruments designed to discover as much as possible during the brief descent.

- Atmospheric Structure Instrument (ASI) — will provide information about temperature, density, pressure, and molecular weight.
- Neutral Mass Spectrometer (NMS) — will analyze the composition of gases by measuring their molecular weight.
- Helium Abundance Interferometer (HAD) — will determine the ratio of hydrogen to helium.
- Nephelometer (NEF) — will locate cloud layers in Jupiter's atmosphere and measure some of the characteristics of the particles which make up the clouds.
- Net Flux Radiometer (NFR) — will sense the differences between the energy flux being radiated inward and outward at each level in the jovian atmosphere.
- Lightning and Radio Emission Instrument (LRD) — will "listen in" on static generated by lightning flashes in Jupiter's atmosphere.

During the 60-minute descent into the jovian atmosphere, the Probe will broadcast the data it gathers to the Orbiter, which will then beam it to Earth.



JPL/NASA

certainly did not answer all our questions about the giant planet and its satellites. But their data directed and refined the questions scientists now ask. Galileo's investigations will perhaps provide the answers.

Voyager made crude and indirect measurements of the elements and compounds that make up the jovian atmosphere. Galileo's Probe will sample the atmosphere directly. But even a direct determination of the atmospheric composition will not give us the bulk composition of the entire planet. Deep within Jupiter, separation processes concentrate heavier elements — carbon, oxygen, silicon, sulfur, nickel, and iron — into a rocky core. The atmosphere will

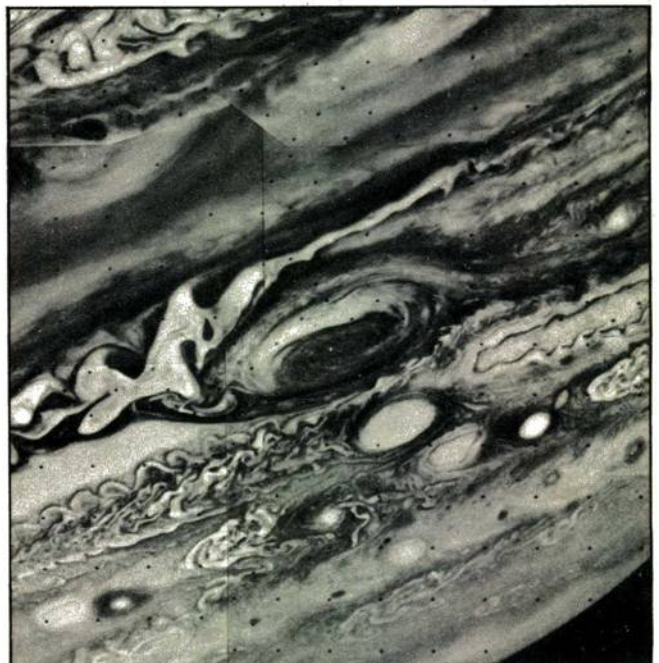
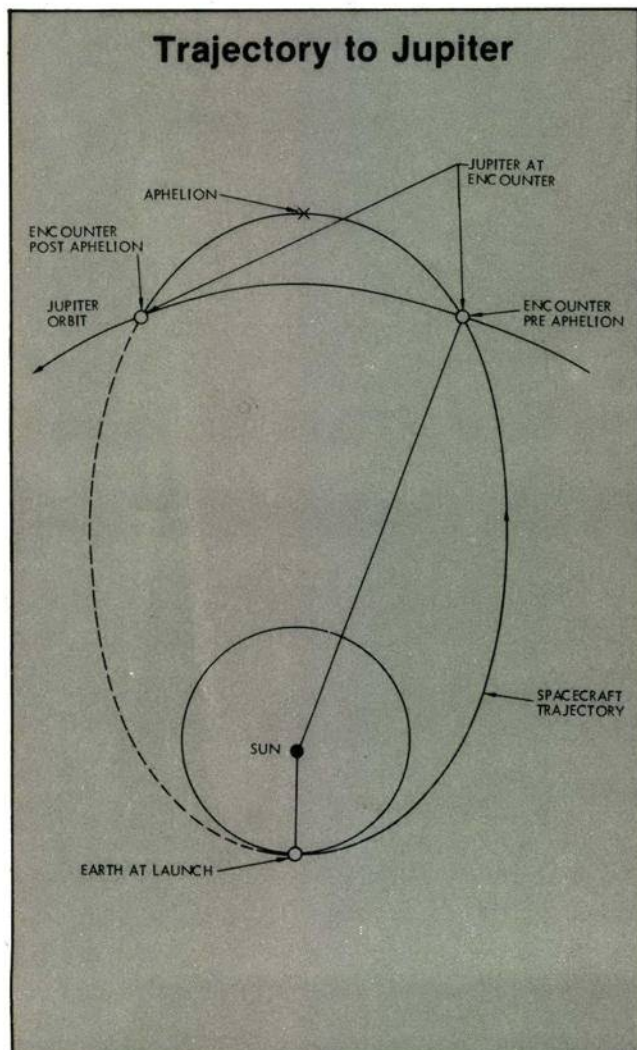
thus hold less of these elements than the Sun does.

However, scientists can indirectly find the abundances by accurately determining the mass and gravitational field of the planet, and using those data to deduce the size and mass of the core. They can then model the total abundances of heavy elements in the planet. These can be compared to measured solar abundances to see if differences exist.

Since the molecular escape time from Jupiter is much longer than the age of the universe, we would expect Jupiter to have sunlike abundances of carbon, oxygen, nitrogen, and helium if the primordial solar nebula were uniform. Deviations from solar abundances would indicate that the local conditions in the solar nebula where Jupiter formed were different from those where the Sun formed. Or perhaps preferential collection processes occurred during planetary formation, which differentiated the solar nebula. Whatever its instruments find, the Galileo mission will provide important keys to understanding the history of the solar system.

Voyager measurements determined that Jupiter's helium abundance is the same as the Sun's to within approximately 25 percent. If the more refined Galileo measurements show that it is very nearly the same, astronomers can safely assume that Jupiter has preserved a sample of the primordial gases. This conclusion could, in turn, be applied to determining the age of the universe. The deuterium (hydrogen-2) abundance depends very critically on conditions following the Big Bang. But where can we look to find a well-preserved sample of hydrogen and deuterium? Deuterium is "burned" in the Sun to produce helium-3, so solar abundances tell us nothing about the primordial deuterium production. Since nuclear burning does not occur on Jupiter, the jovian deuterium abundance could help tie down a crucial cosmological loose end.

Then there's jovian meteorology. Understanding Jupiter's atmosphere and internal structure is an extremely complex task, complicated by several factors including the rate and location of energy





Michael Carroll

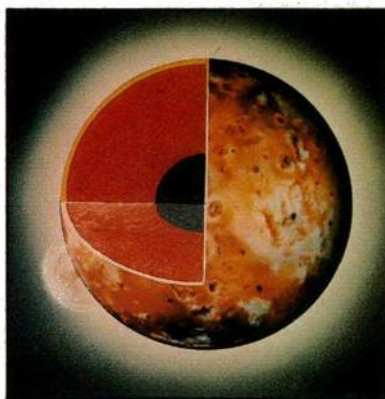
deposition in the atmosphere. Estimates of the ratio of emitted energy flux to absorbed energy flux lie between 1.7 and 2.5. This indicates that Jupiter emits more energy than it absorbs from the Sun. The vertical profiles of radiative heating are, of course, strongly affected by atmospheric composition and cloud location and properties. The vertical and horizontal distribution of solar and internal energy deposition in the atmosphere is the primary source of energy for both large scale dynamics — belts and zones — and for local convection processes — red spots, white ovals and plumes.

Satellite Science

Most models of Jupiter's satellites assume that Io, Europa, Ganymede, and Callisto were formed by the same processes in the jovian nebula that led to the formation of the planets within the primordial solar nebula. These models also suggest that the heat from proto-Jupiter drove off volatiles from the forming proto-satellites. In the case of Io, the heat from the central body prevented water from condensing and left this moon dry and sulfurous.

The jovian system exhibits characteristics similar to the solar system. The Galilean moons decrease in density with distance from Jupiter. Io, the closest, is most dense — 3.5 grams per cubic centimeter. Callisto, the outermost, is the least dense — 1.8 grams per cubic centimeter.

Jupiter raises tides on its satellites. Tidal action heats a planet because tidal energy must be dissipated through friction. The amount of heating varies dramatically: Io receives a great deal of internal heating and the other three receive much less. This difference should result in a pronounced degree of geological activity on Io, less on Europa and Ganymede, and the least on Callisto. By observing the four Galilean satellites on a single space mission, we can observe a system of planets, each with some



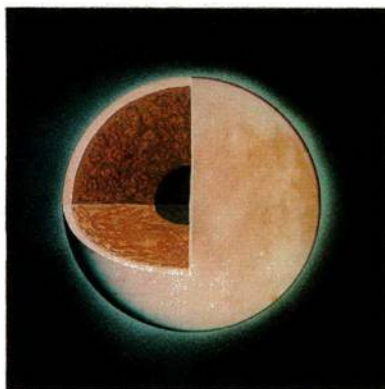
Volcanic Io has an interior of molten silicates and a thin crust rich in sulfur and sulfurous compounds.

different degree of geological activity.

Voyager showed that Callisto, its surface saturated with craters, has been geologically dead since its formation some 4.5 billion years ago. Although Callisto's surface composition is unknown, its density and crater size and shape suggest a rock-ice composition with a rock-ice crust devoid of surface plate motions or volcanic activity.

Before Voyager, astronomers thought Ganymede was similar to Callisto. Their densities are nearly identical, and they receive about the same internal tidal heating. But Voyager discovered some astonishing differences: not only does Ganymede have mountains and valleys, but its surface apparently exhibits "plate" motion similar to continental drift on Earth. Its diverse surface indicates different periods of geological activity.

By contrast, Europa's geology is completely



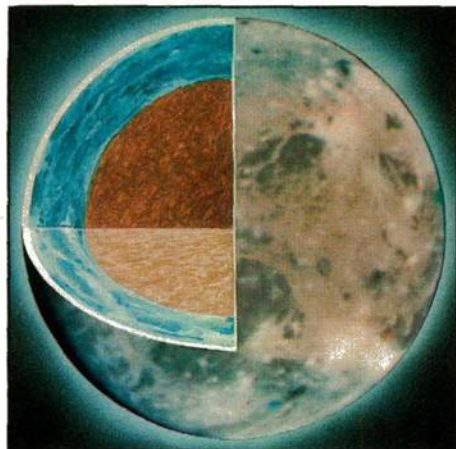
Europa, the smallest of the jovian satellites, has a rocky interior with an icy crust probably less than 100 kilometers thick.

unknown. Its surface is smooth, with no craters, no mountains, and no valleys. This suggests a resurfacing mechanism that eradicates any relief. Water, in the form of ice, has been identified on the surface of Europa, and high reflectivity further suggests an icy crust.

Voyager's remarkable discovery of eight active volcanos on Io lends strong support to the tidal

heating theory, and explains the virtual absence of craters. Material expelled from the volcanic vents could have obliterated the heavy cratering which Io should show. Sulfur dioxide gas was discovered above the volcanic vents by Voyager's infrared spectrometer. This supports the notion that Io's

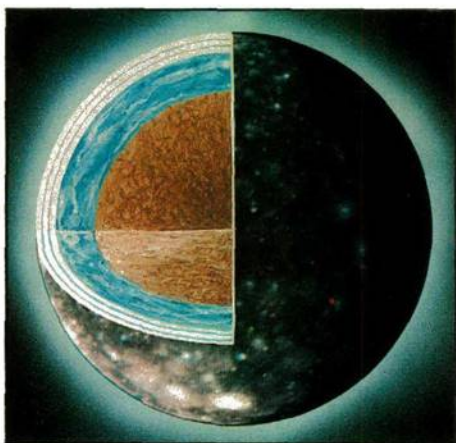
The largest of the Galilean satellites, Ganymede is made of a rocky core, a deep ice or water mantle, and an icy crust less than 75 kilometers thick.



volcanos spew sulfur and oxygen — elements that are observed throughout the entire jovian magnetosphere — into space.

But there is much more to investigate. Except for water on Europa and Ganymede, and sulfur and sulfur dioxide on Io, the surface composition of the satellites remains undetermined. Galileo is well equipped for the job, and global mapping of each of the moons is a high priority of the mission.

Callisto's heavily cratered ancient crust is a mixture of ice and rock, frozen rigid. Supporting it is a mantle of ice or perhaps even liquid water over a core of rock.

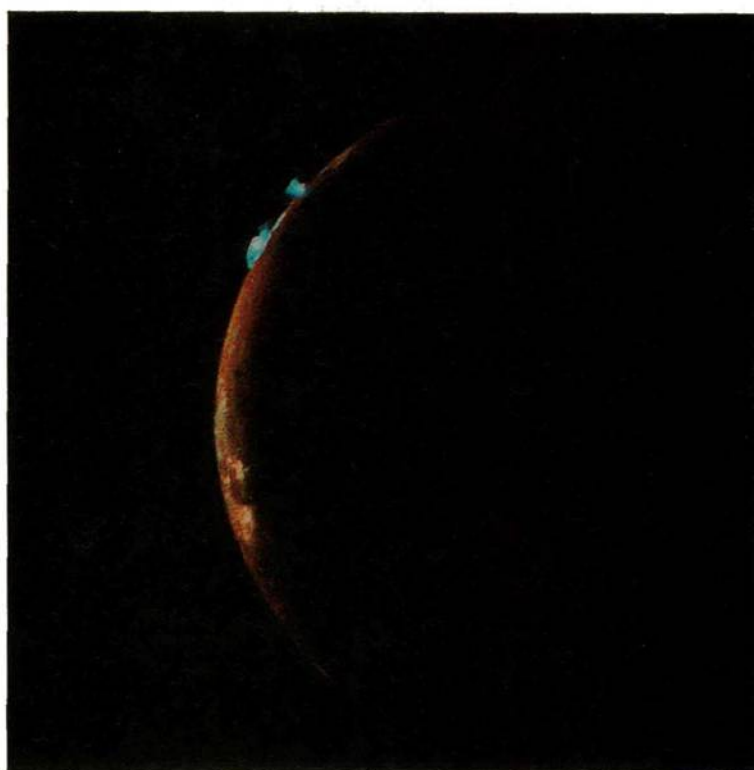


Other objectives include a better understanding of the mechanism driving Io's volcanism, the geology of Europa and the mechanism which apparently resurfaces it, and the reasons for the radically different evolutionary paths followed by Ganymede and Callisto.

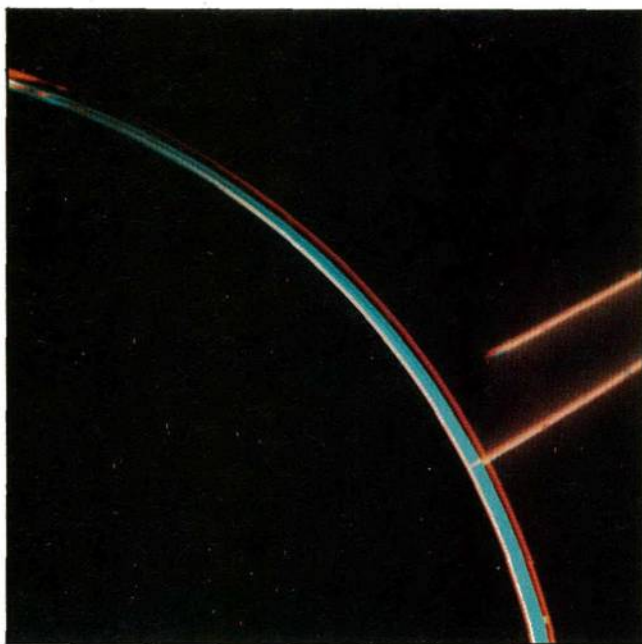
The Jovian Ring

Planetary ring systems have fascinated and confounded astronomers since Christiaan Huygens first described the ring system of Saturn in 1655. In light of the Voyager missions' detailed study of Saturn's rings in 1980 and 1981, Galileo will test emerging theories of ring formation, structure, composition and dynamics. The Jupiter ring system, discovered by Voyager in 1979, will be the test subject.

From the Voyager imagery — plus some educated extrapolation — the following picture of



the jovian rings has emerged. The outer edge of the rings — which ranges from 30 to less than one kilometer thick — is about 57,000 kilometers above the jovian cloudtops. The bright portion of the rings extends inward about 6,000 km, with the outer 800 km relatively brighter than the inner parts. A faint sheet of material extends inward all the way to the jovian

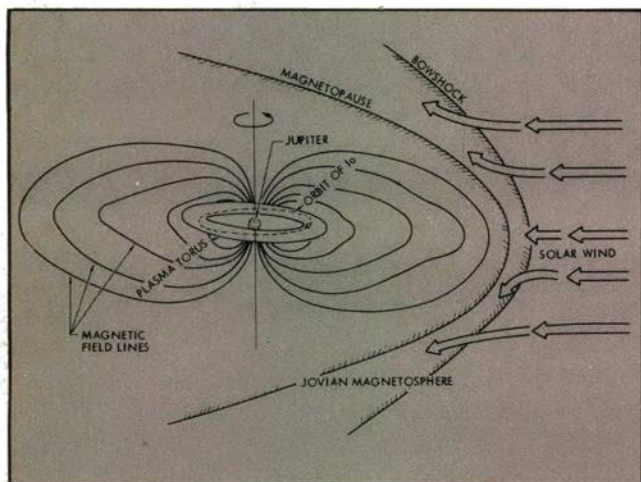


cloudtops, indicating that material from the rings continually falls into Jupiter's atmosphere.

Analysis of Voyager images suggests the ring is composed largely of dust-grain-sized particles around five microns — about 0.0002 of an inch — in diameter. While their composition is not known, comparison of the spectra of the rings with known spectra of water, methane and ammonia ices suggests

that they are not made of icy materials.

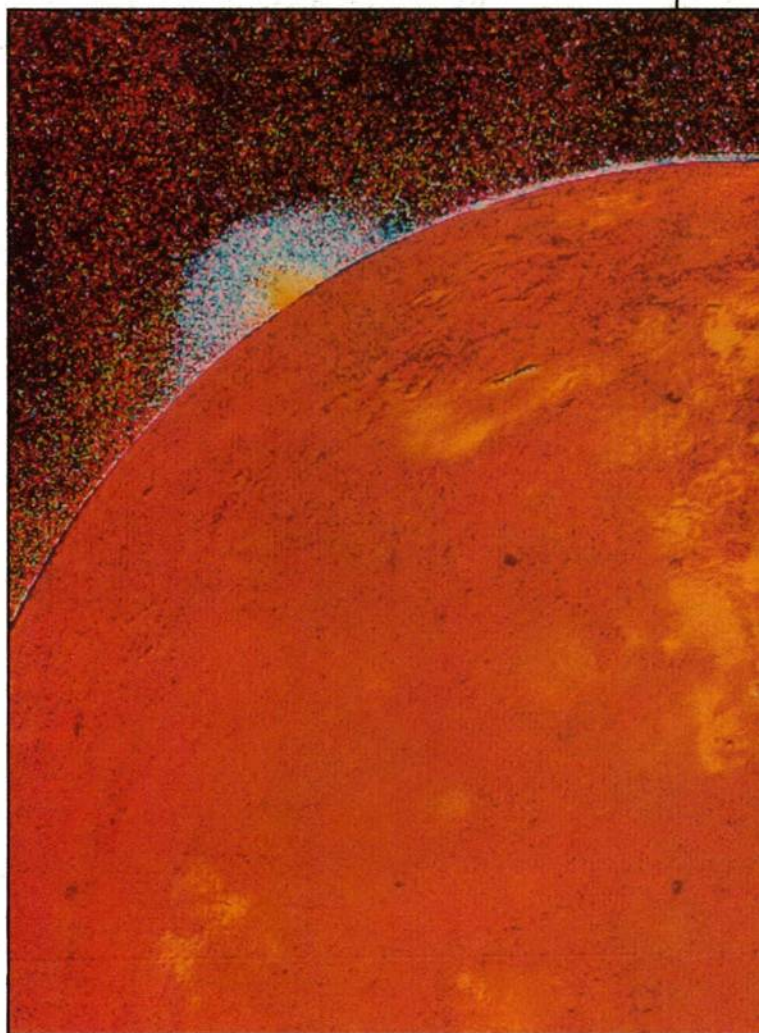
Galileo will conduct simultaneous observations of the rings and their associated newly-discovered moons from about one-third the closest distance reached by Voyager. In addition, scientists will examine the Galileo data to learn the roles of the newly discovered moons Metis and Adrastea in renewing and shaping the rings. Galileo's more sensitive camera will obtain pictures with almost 50 times the Voyager resolution. The NIMS instrument will obtain composition data for both the rings and the new satellites, and the PPR instrument will determine the size distribution and texture of the ring material.



Jupiter's Magnetosphere

Jupiter, with its very high rotation rate and strong magnetic field, offers humans a chance to explore exotic processes. The jovian magnetosphere — a vast swarm of atomic particles moving in the magnetic field of the planet — is dominated by rotational effects. The power necessary to drive its radiation belts, magnetosphere, and the torus in Io's orbit comes largely from Jupiter's rotational energy. Closer to home, the solar wind provides the energy for Earth's magnetosphere. Jupiter resembles rapidly rotating stellar objects such as pulsars, although its rotation rate and magnetic field are much weaker than those of a pulsar. However, the study of the jovian magnetosphere can provide insight into many astrophysical phenomena which we could not otherwise directly observe.

The jovian satellites and Jupiter's magnetosphere are closely coupled. Processes on the satellites probably cannot be understood without considering the effects of the rapidly rotating magnetosphere. The magnetospheric dynamics, in turn, are closely coupled to satellite processes. For example, Voyager observations show that Io's volcanos are probably a source of sulfur dioxide. This gas escapes into space, becomes dissociated and ionized to form a ring-like cloud of neutral and ionized gases along Io's orbit. As Jupiter spins, its magnetic field also spins, pulling the charged particles along with it. If they reach the same spin rate as Jupiter, they become co-rotating. Of course, the farther from Jupiter, the greater the actual speed of co-rotation. Jupiter thus accelerates the ions, and the major energy input to the torus ultimately comes from Jupiter's rotational energy.



But important questions remain unanswered. The combined observed energy dissipation due to ultraviolet radiation from the torus, aurorae on Jupiter, and magnetospheric wind appears to be greater than can be supplied by rotational energy transfer into the Io torus. Then where does the energy come from? If, for example, energy transfer occurs over a greater volume than the torus, then these regions must rotate more slowly than the co-rotation rate — otherwise the field couldn't be supplying them with energy. Voyager's measurements were ambiguous on the co-rotation question in the middle magnetosphere.

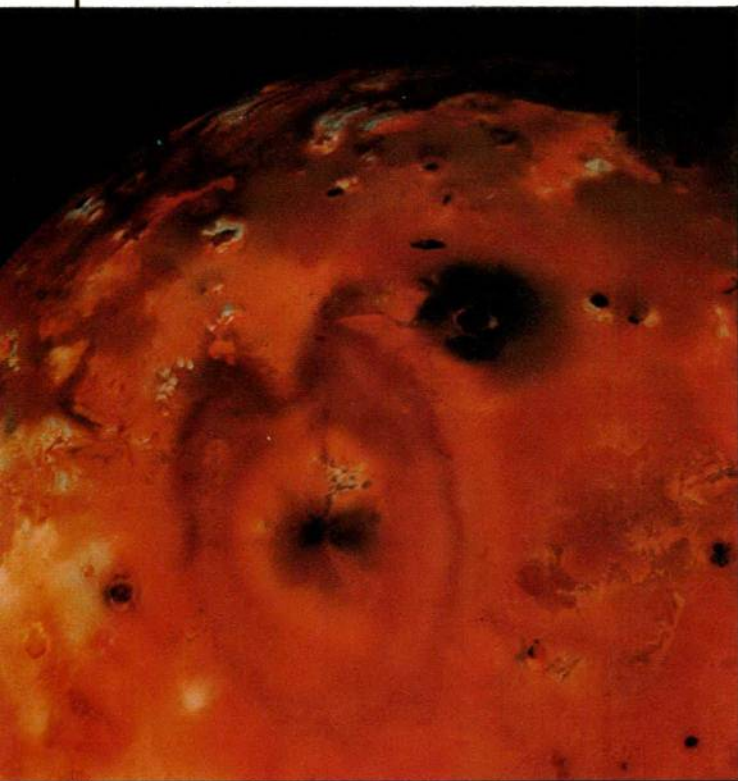
Galileo's Orbiter will spend nearly two years tracing out a variety of elliptic trajectories throughout the jovian magnetosphere. On each orbit the spacecraft will pass into the middle magnetosphere, and by virtue of its mass analysis capabilities for low energy particles, should be able to resolve the co-rotation issue.

Observation of Io's volcanic activity and torus can be made over the full two-year period, and, when coupled with jovian auroral observations and magnetospheric measurements, should provide the information we need to understand the extremely complex processes of the jovian system.

Arrival at Jupiter

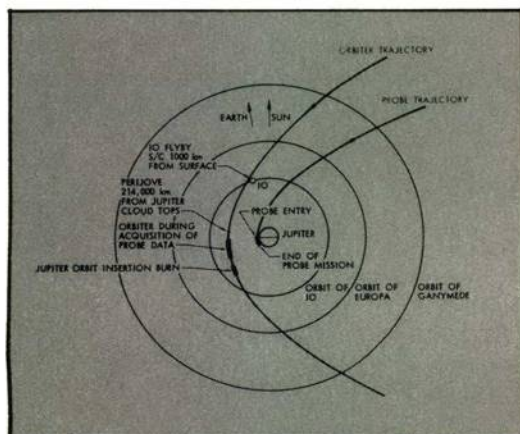
When Galileo is about 150 days and 150 million km from Jupiter, the Orbiter will release the Probe. Since the Probe has no maneuvering capabilities of its

own, its targeting at time of release must be extremely accurate. If all goes well it will enter the jovian atmosphere with a latitudinal error of less than 800 kilometers. This is comparable to striking a target one foot in diameter with a bullet fired from 25 miles away — excellent marksmanship indeed.



Following Probe release, the Orbiter will maneuver to keep from following the Probe into the planet. This deflection will target the Orbiter to pass Jupiter about 230,000 km above the cloudtops at the same time the probe streaks into the jovian atmosphere at a sizzling 48 kilometers per second.

Four hours before the Probe mission begins, Galileo will pass within 1,000 kilometers of volcanic Io — 20 times closer than the Voyager 1 flyby in 1979. This will be the only close flyby of Io during the entire Orbiter mission. Io's gravitational attraction will assist in slowing the Orbiter, and permit Jupiter to capture the spacecraft in orbit. One-time-only high resolution remote sensing as well as charged particle measurements will help determine the composition of the Io surface and the mechanisms by which the Io

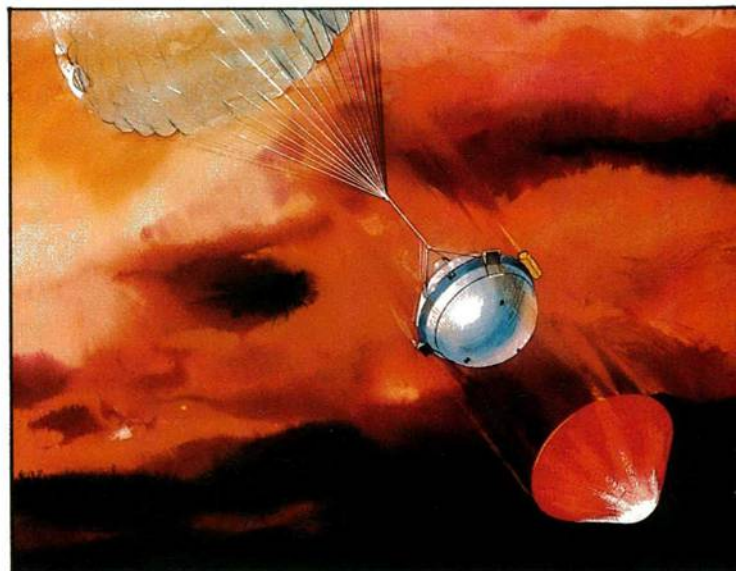


volcanos feed the torus. Radio science measurements will help chart the shape of the moon and the mechanism by which the volcanism occurs. Finally, the magnetometer will measure the strength of the magnetic field scientists have postulated for Io.

Meanwhile, the entire array of fields and particles instruments will probe the interaction of Io with the jovian magnetosphere as the spacecraft passes through the wake Io plows in the torus. This wake, which leads Io, is formed because the jovian magnetosphere and radiation belts rotate faster than Io by 57 kilometers per second at Io's orbit.

About four hours after the Io science sequence, and only minutes after the spacecraft's closest approach to Jupiter, the Probe will enter the jovian atmosphere and relay data upward to the Orbiter. Both flight paths must be synchronized so the Orbiter can receive and relay the signals to Earth from the Probe as it descends.

The Probe will provide the first direct sampling of Jupiter's atmosphere. Its entire mission will last 60 minutes at most as it descends from the outer fringes to a depth where the pressure is about 10 bars, or 10 times the atmospheric surface pressure on Earth.



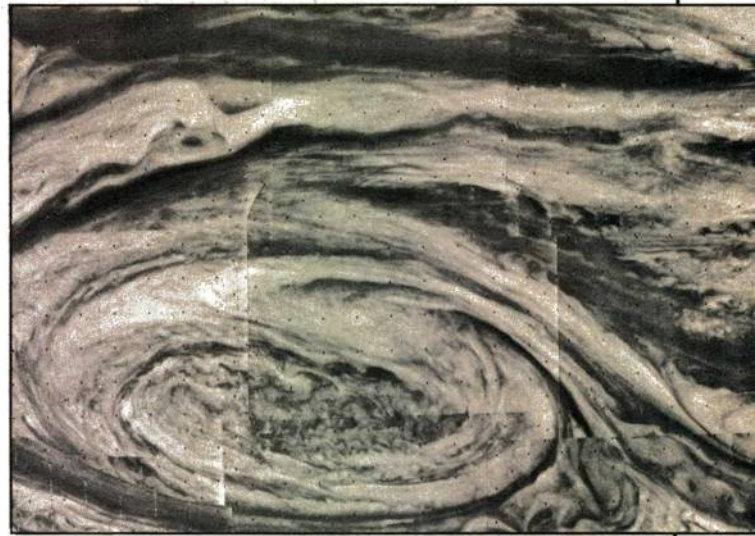
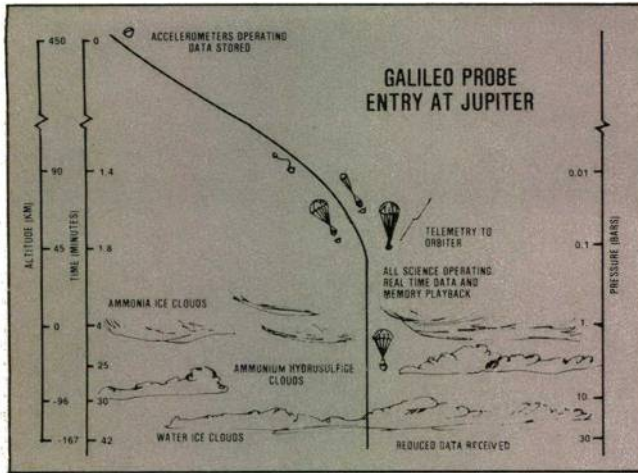
JPL/NASA

When it strikes the upper layers of the atmosphere, the Probe will be traveling at about 48 kilometers per second. As it reaches peak deceleration, it will be subjected to a force of 400 Gs — or 400 times Earth's gravity. The 360-pound ablative heat shield surrounding the Probe makes up more than half of its entire weight and protects its delicate instruments. It will keep the Probe from burning up as it enters the jovian atmosphere at such great speed. Once the strongest deceleration passes, the Probe will deploy a parachute and begin its atmospheric measurements.

The probe's angle of entry — established when it separates from the Orbiter — must lie between -7° and -10° relative to the horizontal. Shallower entry angles could allow the Probe to skip off the atmosphere and back into space — like a flat stone skipping off the surface of a pond. A steeper angle could overheat the shield or damage the Probe instruments. Current estimates require the shield to withstand a temperature of $6,000^\circ$ Fahrenheit.

Around 220 pounds of shield material will burn off during entry.

The speed of the Probe relative to Jupiter as it nears entry will be about 60 kilometers per second. At this rate, the Probe could fly the length of the United States in only 90 seconds — and a shield adequate to protect it would be prohibitively heavy. Designers of the Galileo mission, however, have nature on their side. Since Jupiter rotates once in about 10 hours, the speed of the atmosphere at the one bar level is about 12 kilometers per second. The Probe trajectory will take advantage of Jupiter's rotation by entering in the same direction the planet spins. This will reduce the speed of entry to a safe 48 kilometers per second.



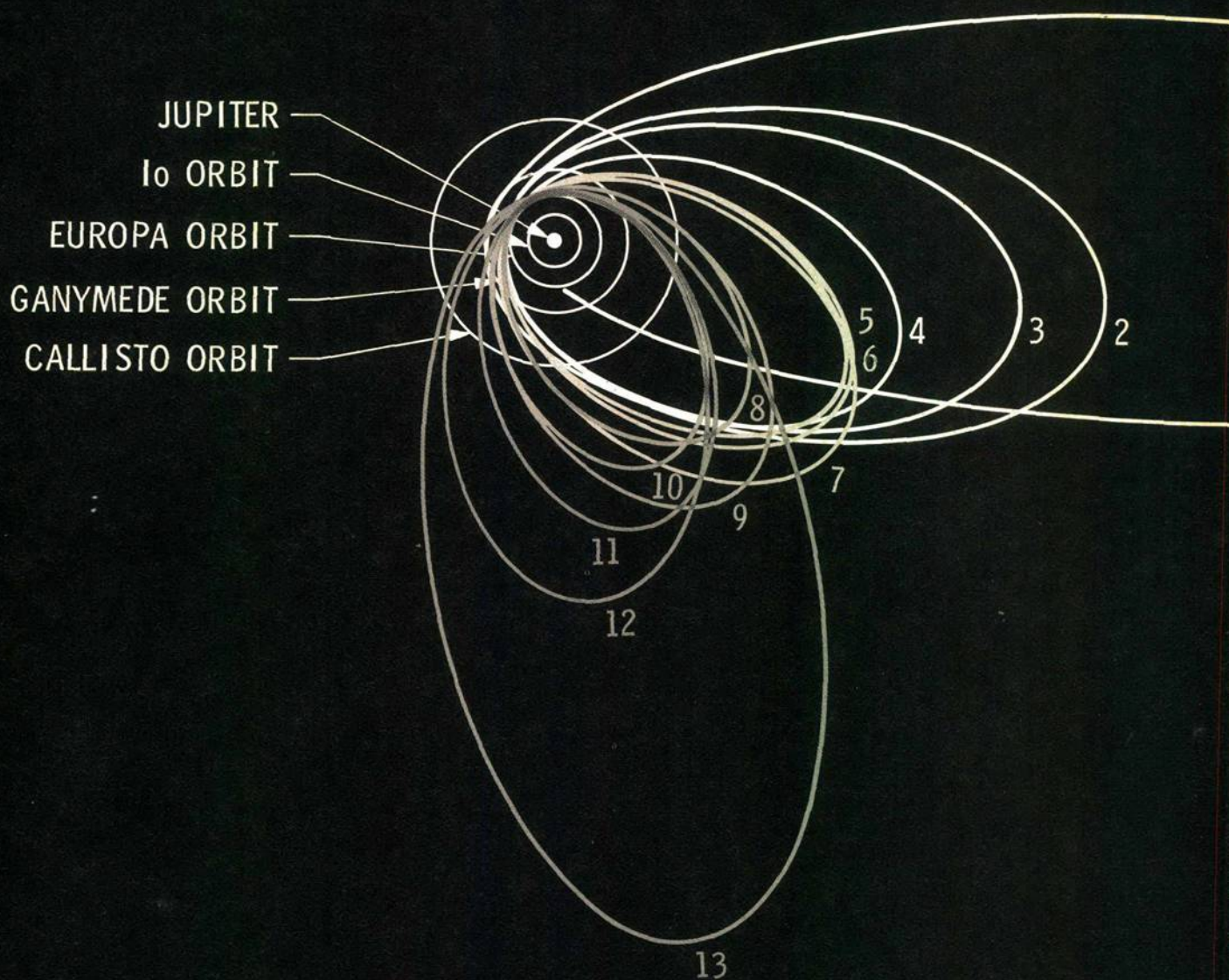
Following the conclusion of the Probe mission, the Orbiter's retropropulsion motor will ignite. Galileo's velocity relative to Jupiter will then drop from 30.5 kilometers per second to 29.5 kilometers per second. Coupled with a gravity assist from Io, this will allow Jupiter to gravitationally capture the spacecraft.

Galileo will enter a long looping trajectory about Jupiter with a period of 200 days. The *apojove* of the orbit — the farthest distance from Jupiter to the spacecraft — is about 20 million kilometers. The Orbiter is about to begin its epic tour of the Jupiter

SPACECRAFT TOUR OF THE JOVIAN SATELLITES

ENCOUNTER NUMBER	MOON	ENCOUNTER GEOMETRY	ENCOUNTER ALTITUDE (KM)	LATITUDE AT CLOSEST APPROACH
Jupiter Orbit Insertion Phase	Io	Inbound, outside	1,000	1° S
1	Ganymede	Inbound, outside	900	11° N
2	Ganymede	Inbound, polar	500	74° N
3	Ganymede	Outbound, inside	3,600	12° S
4	Callisto	Outbound, inside	3,800	9° S
5	Europa	Outbound, polar	1,000	89° S
6	Callisto	Inbound, polar	2,400	63° S
7	Callisto (non-targeted)	Inbound	64,600	5° S
7	Ganymede	Outbound, inside	400	34° S
8	Europa	Inbound, inside	200	5° S
8	Ganymede (non-targeted)	Outbound	39,700	0°
9	Europa (non-targeted)	Outbound	53,200	1° S
9	Ganymede	Outbound, inside	2,400	2° S
10	Europa	Inbound, inside	500	20° S
11	Callisto	Inbound, inside	1,100	16° S
12	Ganymede	Outbound, outside	300	0°

Galileo's Tour of the Jovian Satellites



system.

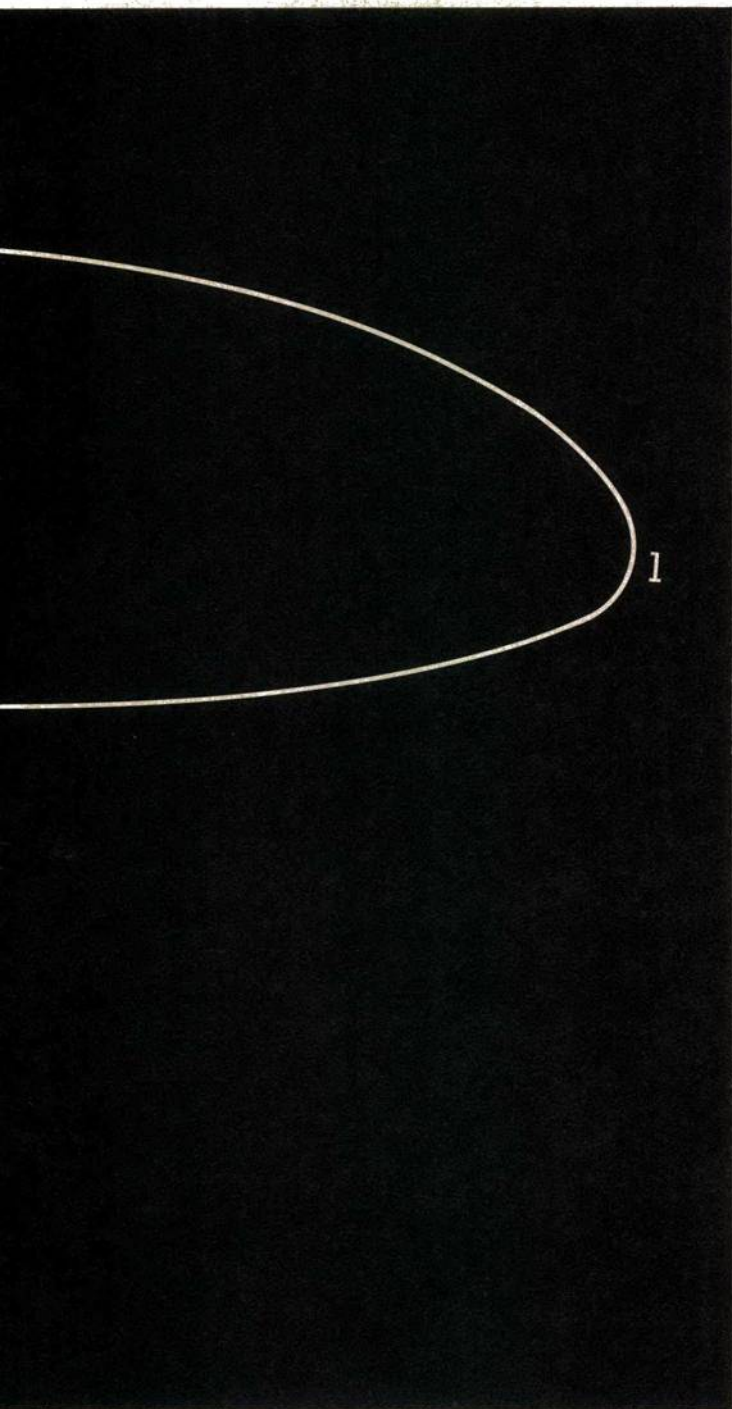
The Tour Design

The spacecraft's tour through the jovian system consists of 12 orbits over a period of 20 months. The scientists and engineers who have designed it plan to accomplish a wide range of what appear to be mutually exclusive science objectives. Their challenge lies in plotting a complex flight path through the jovian magnetosphere, changing the orbit many times, and passing close to satellites over a dozen times — all without using a lot of fuel. How will they do it?

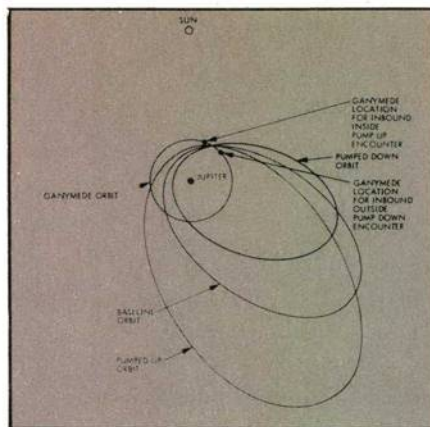
They'll use flybys of satellites to assist them in shaping the trajectory. On-board propellant will be saved for fine-tuning. The moons, by a factor of 30 to 1, provide the energy to shape and orient Galileo's trajectory. The cue-ball spacecraft will carom through

twelve close encounters using the gravity assist from one encounter — say with Ganymede — to guide the spacecraft to the next — say with Europa — some 30 days later. Flyby ranges of less than 500 kilometers, and accuracies of better than 75 kilometers, will be orchestrated from Earth — 750,000,000 kilometers away.

How can close encounters shape an orbit? From a strictly trajectory point of view, there are basically only four types of spacecraft encounters with the moons — an inside equatorial pass, an outside equatorial pass, and a north or south polar pass. On an inside equatorial pass, the spacecraft flies between the moon and Jupiter. On an outside equatorial pass, its trajectory takes it outside the moon with respect to Jupiter. On a polar encounter, the spacecraft passes directly over the north or south pole.

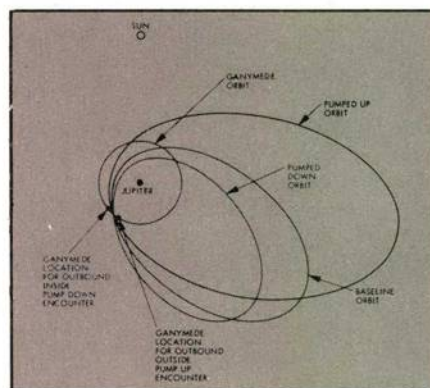


Consider the case where the spacecraft encounter with a satellite occurs before the spacecraft arrives at *perijove* — closest to Jupiter. This encounter is on the “inbound leg” of the trajectory. If, on the inbound leg, the spacecraft makes a close equatorial pass outside the moon, or farther from Jupiter than the jovian satellite, then the gravity of the moon bends the spacecraft trajectory so it passes closer to Jupiter than it would have without the encounter. This lowers the *perijove* of the orbit — a result of the moon removing energy from the spacecraft. Energy loss lowers both *perijove* and *apojove* of the spacecraft orbit, so the period of the orbit is shortened, or, “pumped down.” The new closest approach point is such that the *line of apsides* — the semimajor axis of the orbit — has been rotated in a counterclockwise direction.



Scientists will use close flybys to control the trajectory of Galileo. On the inbound leg of an orbit, depending on whether the spacecraft makes an inside or outside pass, the encounter can expand or contract the orbit.

Incidentally, the conservation of energy requires that the energy removed from the spacecraft during its passage near a satellite be picked up by the moon — in other words, the total energy of the spacecraft and moon combined must remain constant. The resulting velocity increase caused by a 500 kilometer inbound/outside/pumpdown flyby of Ganymede by Galileo would be about 10 meters per trillion years for Ganymede.



On the outbound leg of an orbit, an encounter with a satellite can expand or contract the spacecraft orbit — depending on whether it makes an inside or outside pass. Close flybys give the instruments aboard the Orbiter a chance to make detailed studies of the satellites.

Next, consider the case where the spacecraft encounters the moon on the inbound leg and on the inside of a moon, or closer to Jupiter than the satellite. The close encounter with the moon bends the spacecraft trajectory so *perijove* is greater than it would have been without the close encounter. The spacecraft has picked up energy from the moon, raising both *perijove* and *apojove* of the spacecraft orbit, and the period of the orbit is accordingly increased, or “pumped up.” The location of the new *perijove* point is such that the line of apsides has rotated in a clockwise direction.

We can also use the outbound encounters for orbit shaping and orienting. An outbound/outside pass pumps energy into the spacecraft, increases *perijove* and *apojove*, and thus pumps up the orbit period as well as rotating the line of apsides counterclockwise. An outboard/inside pass removes energy from the spacecraft, decreases *perijove* and *apojove*, and thus pumps down the period. It also rotates the line of apsides in a clockwise direction.

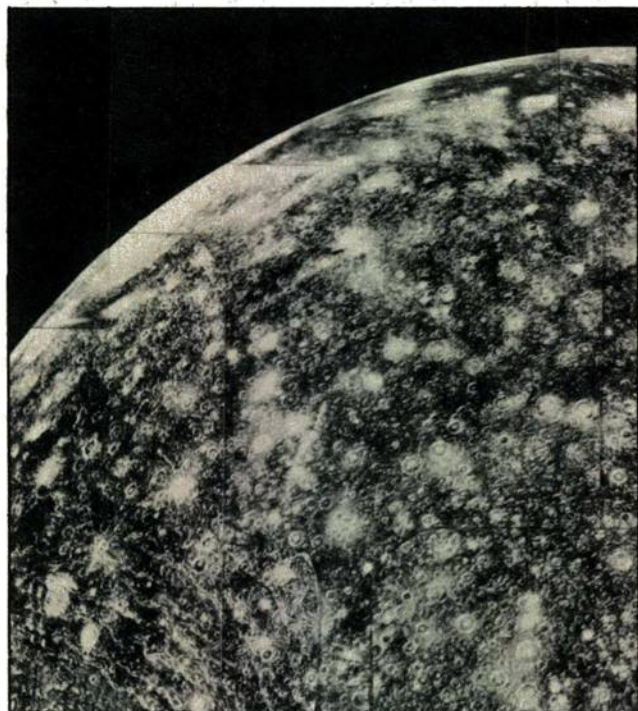
Planning the Galileo Tour

The orientation of Galileo’s first orbit in its tour is fixed by launch conditions. For the planned launch date, the line of apsides nearly coincides with a line drawn through both terminators of Jupiter — at right angles to the Jupiter-to-Sun line. The *apojove* of the

first orbit lies almost directly over the dawn terminator.

Mission planners refer to each orbit as a *petal* and classify it according to the location of its apojove. Thus the first orbit is called a *dawn petal*. In order to achieve a *tail petal*, or a petal in the anti-solar direction within the 20 month orbital mission while also achieving at least 11 close encounters with Europa, Ganymede, and Callisto, the orbital period must be pumped down to 30 days. It also must be rotated 90° from the dawn region to the tail region, and then pumped back up again to achieve a "deep" tail petal extending more than 150 jovian radii — about 11 million kilometers into space behind Jupiter.

Polar passes, either on the inbound or outbound legs, don't measurably change perijove, apojove or



orbital period, or appreciably rotate the line of apsides. However, planetary scientists need polar passes in order to look at the entire surface of each satellite and map them and determine their surface features. Of equal importance are the polar passes that will study interactions between the satellite and the jovian magnetosphere, and measure the masses and mass distribution inside the satellites. Thus, many important scientific goals of the mission require polar passes.

But polar passes cause problems. Although they do not rotate or pump the orbit, they tilt the plane of the spacecraft trajectory with respect to the plane of the satellite orbits. In order to control the trajectory, any tilt in the trajectory plane caused by one encounter, say a south polar pass of Callisto on the inbound leg, must be taken back out of the trajectory by a north polar pass of Callisto on the inbound leg of the next orbit — or by a south polar pass of Ganymede on the outbound leg of that next orbit.

Trajectory Design

The choreography for this cosmic dance through the jovian system is planned years ahead of time. Indeed, at the time of this writing, three years before

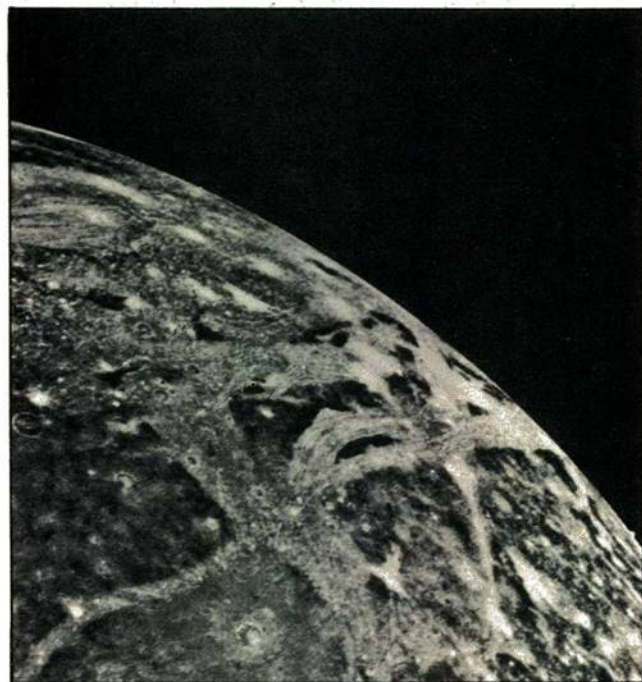
launch and six years before the initial encounter with Jupiter, 50 different satellite tours have been developed at JPL. Each has been reviewed by mission scientists from all over the world, and each has been evaluated for how it satisfies the science objectives of each experiment.

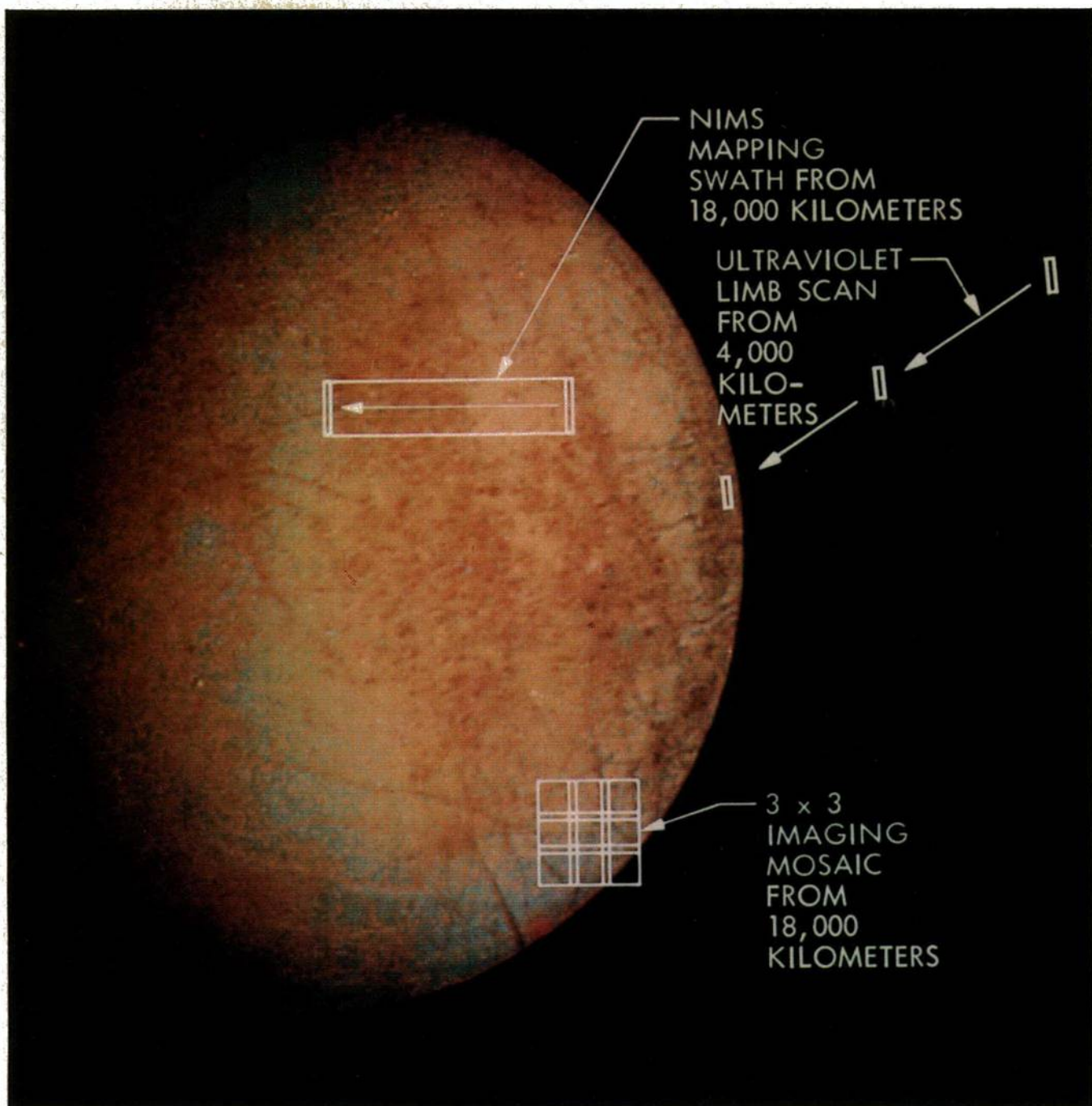
The fields and particles instrument scientists generally want flybys within 1,000 kilometers of the moons to measure the interaction of the moons with the jovian magnetosphere, to probe for inherent magnetic fields associated with the moons, and to measure dust dynamics. In addition to this, the fields and particles scientists want to probe the region of the jovian magnetosphere pushed away from the Sun by the solar wind on the deep tail petal orbit. The celestial mechanics radio scientists also want close flybys so they can perform gravity experiments that should help them determine the masses of the satellites.

While remote sensing instrument scientists need close flybys for high-resolution mapping of the surfaces and potential atmosphere of the moons, they prefer flybys with ranges greater than 5,000 kilometers — ideal for global geological and mineralogical mapping. But closer flybys are required in order to rotate the orbit petal toward the tail from the dawn region where it begins the tour. Distant flybys are much less efficient at rotating the orbit petal toward the tail region. After three years of study and over 50 computer simulated tours, the scientists and mission planners have developed a strategy to accomplish these seemingly incompatible science objectives.

Flying the Tour

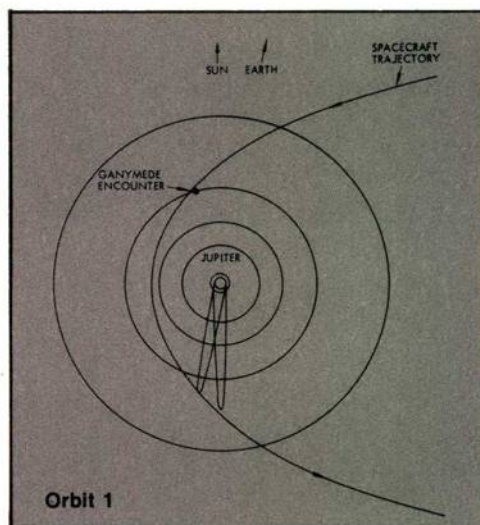
The first close flyby of the tour is a 900-kilometer altitude/inbound/outside/pumpdown/near equatorial flyby of Ganymede. This flyby has a very important strategic objective — reducing the period of the orbit from 200 days to 64 days. Later encounters with Ganymede — the most effective orbit shaping and pumping moon — reduce the period to an average of 30 days per orbit.





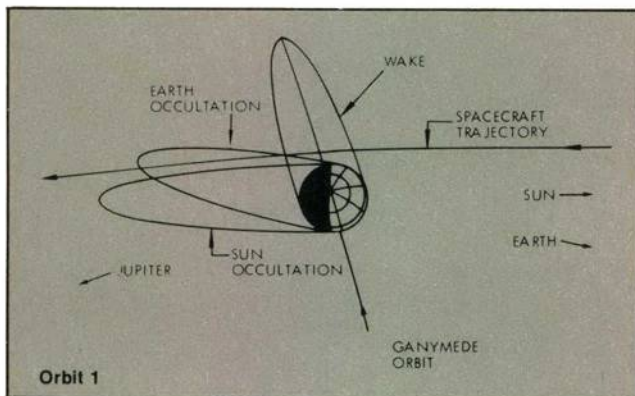
During the approach to Ganymede on this first encounter, lighting conditions will be ideal for high resolution global mapping — with the Sun nearly “over the shoulder” of the onrushing Galileo spacecraft. The cameras and infrared instruments will perform geological and mineralogical studies — making detailed pictures of the strange grooved landscape and slumped craters, and recording detailed spectra of the surface. Fields and particles instruments will probe for a Ganymede magnetic field and measure the nature of the interaction between Jupiter’s magnetosphere and the moon. These experiments will be carried out as the spacecraft passes through the magnetospheric wake region that leads Ganymede in its orbit about Jupiter.

Following the perijove after this initial encounter, the spacecraft — if it could be seen from Earth — would appear to skim just above the north



pole of Jupiter, and its radio signals will pass through the region above the pole. Using the "Faraday rotation experiment" on the transmitted radio beams, astronomers will measure the strength of Jupiter's magnetic field and the number of charged particles trapped around the planet's poles.

To further reduce the Orbiter's orbital period and to bring Galileo's orbital inclination closer to that of the satellites, the second satellite encounter is also with Ganymede. This time the encounter will be a near-polar pass at about 74° north latitude. This high latitude, though not purely polar, inbound/slightly outside/500-kilometer altitude flyby will pump down the orbital period from 64 to 51 days and remove, or "crankdown," the remaining trajectory inclination. While the global mapping science from ranges less than 50,000 kilometers will duplicate that of the Ganymede 1 encounter, the high resolution mapping of this satellite's polar regions from less than 5,000 kilometers will be unique. The fields and particles experimenters will also have a singular opportunity to explore the Ganymede flux tube. Because no Earth occultation of the spacecraft by Ganymede will occur on this encounter, radio science gravity measurements can be made to help determine its interior structure.

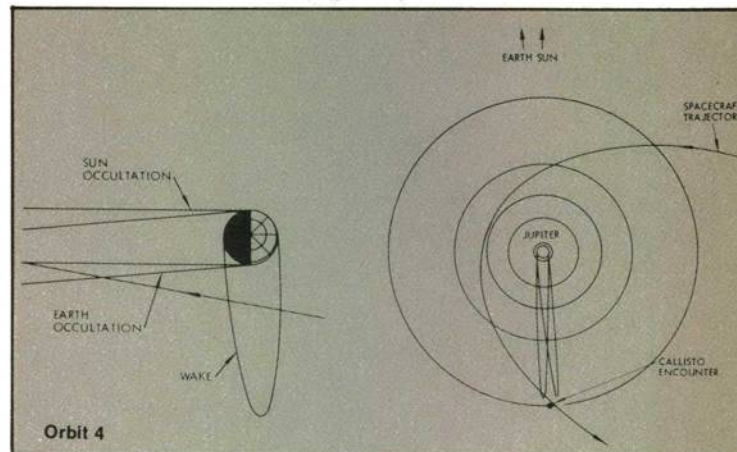


Because the moons of Jupiter are tidally bound to the planet, the same side of each moon always faces Jupiter. This is useful in Galileo's satellite tour. The Sun illuminates opposite hemispheres of a moon for points 180° apart in its orbit around Jupiter, so the orbit planners can aid global mapping by encountering a given moon at nearly opposite points in its orbit. This is the case for the third encounter of the satellite tour.

The encounter is again with Ganymede, only this time it will take place on the outbound leg. The illuminated hemisphere of Ganymede will then be about 130° different in longitude than it was for the first two Ganymede encounters. This outbound, inside, flyby also will pumpdown the orbit period from 51 days to 35 days, and will rotate the orbit toward the tail by 9.5°. This third meeting with Ganymede will also lower perijove to 10.2 jovian radii, and target the orbiter for its fourth encounter, a close flyby of Callisto.

The Callisto 4 flyby will be an outbound/inside/pumpdown encounter that will rotate the line of apsides toward the tail region. The visible disk of Callisto will be almost fully lit during the approach, providing an excellent opportunity for global

mapping. Scientists will study the interaction of Callisto with the jovian magnetosphere during the passage of the spacecraft through the wake leading Callisto in its orbit. Since the encounter altitude for



Callisto 4 will be rather high — almost 4,000 kilometers — dust measurements and probes for a Callisto magnetic field will wait for a closer flyby later in the tour.

After the Callisto encounter, the perijove will be low enough to permit an encounter with Europa, the target of the fifth encounter on the tour. This one — an outbound/1,000-kilometer south polar flyby — will image the surface with a resolution over 200 times greater than the Voyager cameras. Solar lighting conditions on the approach to Europa will be excellent for global and high resolution geological and mineralogical mapping. The close flyby will allow scientists to use the UVS instrument to probe Europa for an atmosphere. The radio science team will perform gravity measurements that could reveal Europa's interior structure, which may be liquid water. Meanwhile, the fields and particles experimenters will study the interaction between the jovian magnetosphere and Europa as the spacecraft passes through the moon's flux tube zone. They will also search for an inherent Europa magnetic field.

The passage under Europa's south pole will

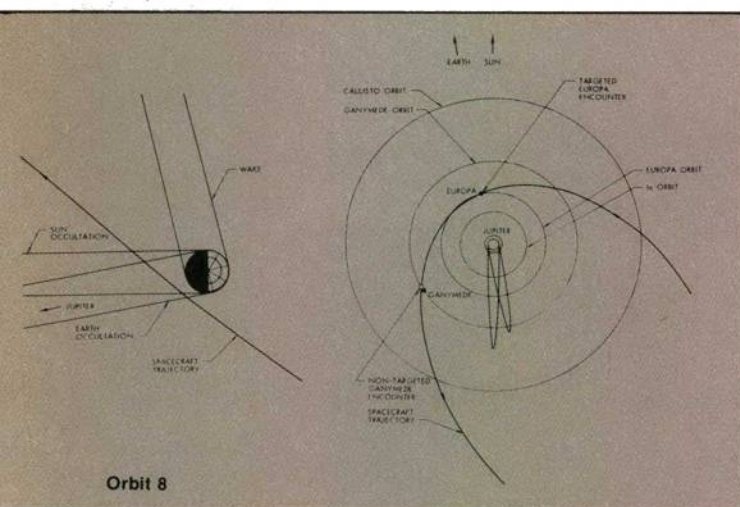


introduce a 2° tilt in the Orbiter trajectory. On the next orbit, the tilt will be taken back out by an inbound/crankdown/63° south latitude/2,400-kilometer altitude flyby of Callisto — the sixth close encounter. This will provide a look at the other side of Callisto for global and high resolution mapping of Callisto's ancient and densely-cratered surface. The fields and particles experimenters will investigate a possible magnetic field, and study the interaction between the jovian magnetosphere and this icy body as the spacecraft passes through Callisto's flux tube zone.

The next several encounters alternate between close Europa and close Ganymede flybys. The solid state camera will map more than half of Europa's surface, providing invaluable pictures of its enigmatic "cracked" surface. The Ganymede flybys rotate the line of apsides toward the tail. Accordingly, this pass near Callisto will target the spacecraft for its seventh close flyby — a 433-kilometer altitude/outbound/inside pass by Ganymede which will rotate the orbit petal 12° toward the tail.

This orbit will also feature a *non-targeted encounter*. Such encounters aren't needed for controlling the orbit — they simply happen. However, they provide valuable additional opportunities to map the satellites. This one is a 64,600 kilometer altitude pass of Callisto on the inbound leg. Because Callisto's orbital period is not in resonance with the periods of other Galilean moons, non-targeted passes with this moon are truly chance encounters — they cannot be planned.

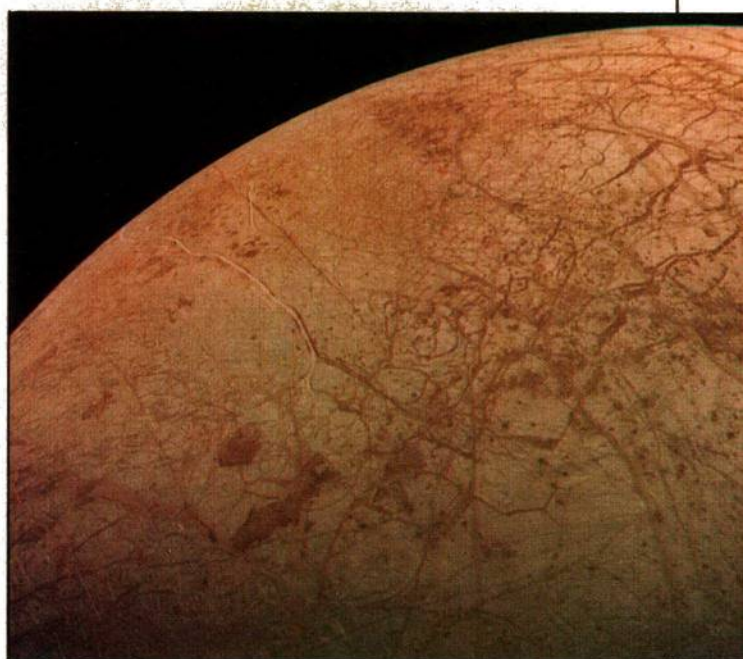
However, because of the near-resonance of the orbit periods of Europa (at 3.551 days) and Ganymede (at 7.155 days), non-targeted encounters with those moons are possible over several orbits. Opportunities for non-targeted encounters occur on the eighth



orbit with Ganymede, and on the ninth orbit with Europa.

The targeted encounter for the eighth orbit is with Europa. The non-targeted distant encounter with Ganymede is a 39,700 kilometer closest approach following the targeted close Europa flyby.

The non-targeted Europa pass will approach within 53,200 kilometers on the inbound leg of orbit 9 prior to the targeted Ganymede 9 encounter. It will provide the geometry and lighting to fill the gaps in



the maps not covered in the targeted encounters. In addition, during the Europa orbit 8 and orbit 10 encounters, the spacecraft will pass into the Earth occultation zone, and provide radio scientists an opportunity to probe for and characterize the moon's atmosphere — if it has one.

The Europa orbit 10 encounter will target the spacecraft for a Callisto encounter on the inbound leg of the eleventh orbit. The primary purpose of Callisto 11 — a 1,100-kilometer altitude/inbound/inside pass — is to complete the orbit rotation and begin to pump up the orbit for the deep-tail petal. Following Callisto 11, the orbit orientation will be 172° with respect to the Sun, with an apojove of 79 Jupiter radii. This is substantially less than the required 150 Jupiter radii for the tail petal. The final encounter — an outbound/outside/300-kilometer altitude pass of Ganymede — will pump up the orbit to 155 Jupiter radii, and send Galileo out on its long tail petal orbit. The fields and particles experimenters will use this long orbit into the trailing "wind-sock" region of the jovian magnetosphere to study how the magnetic field behaves when it is stretched away from the planet and to learn the ultimate fate of the atoms that lo spews from its volcanos.

The final encounter could have been targeted as an inbound/inside/Ganymede pass, which, in addition to pumping up the orbit appropriately, would have rotated the petal farther tailward. However, in order to complete the radio science gravity measurements of Ganymede, the scientists needed an equatorial non-Earth occulted flyby. This eliminated the inbound/inside pass. The primary Galileo mission ends with the completion of the tail petal orbit of the satellite tour.

Winding Down

After Galileo has completed its primary mission, the scientists and mission strategists have several options — mutually exclusive options — open to them. They may continue to rotate the orbit toward the dusk hemisphere, an option which would permit the fields and particles scientist to map the jovian magnetosphere from dawn to dusk.



Painting by Michael Carroll

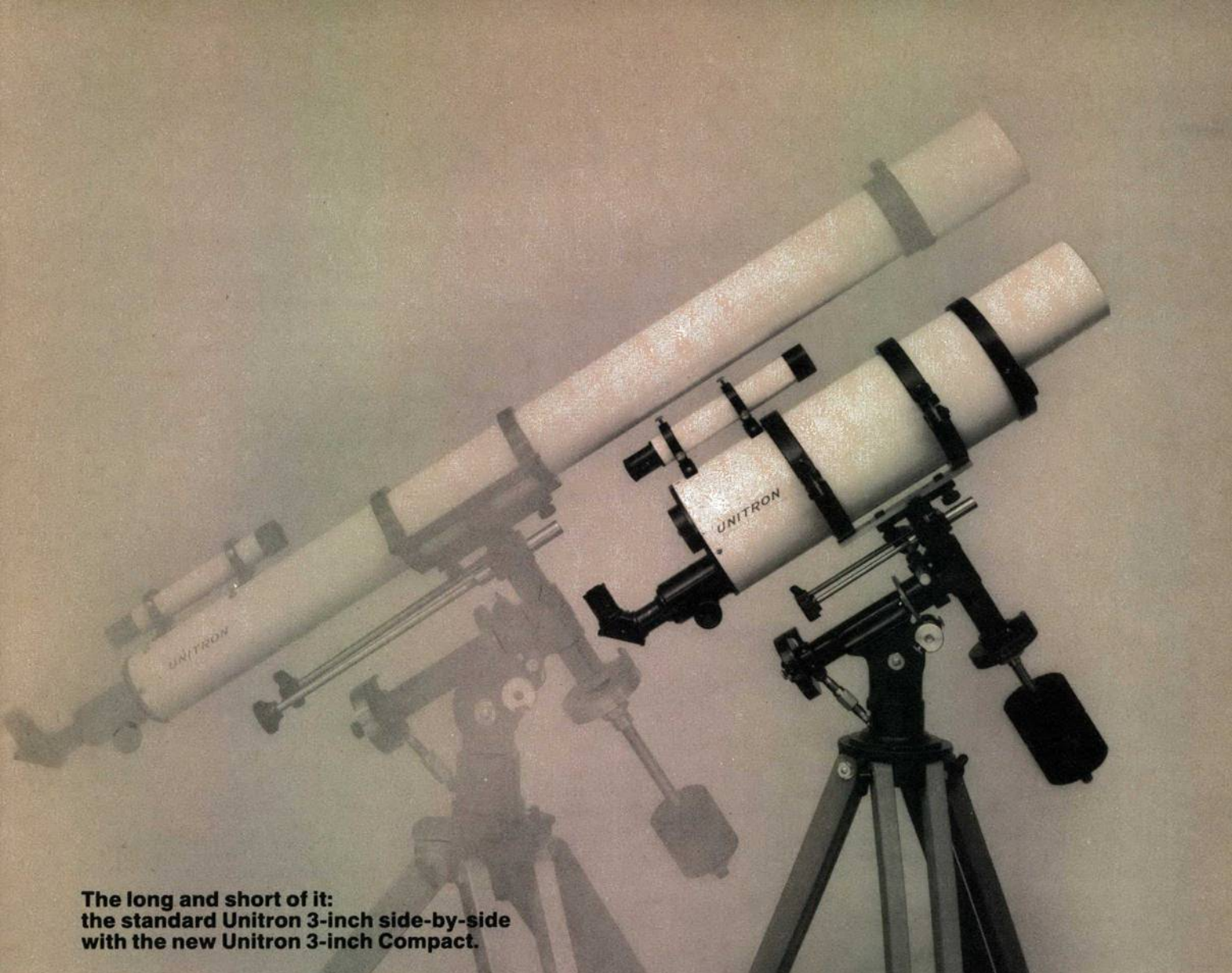
They may also “crank up” the orbital inclination to allow high latitude observations of Jupiter’s atmosphere. Scientists whose interests lie in the energy balance of the giant planet and meteorologists favor this option.

Finally, they could lower the orbit’s perijove and allow Galileo to approach Io more closely. The satellite scientists would very much like an opportunity to study Io, the only body in the solar system besides Earth to have active volcanos.

Which will it be? The principal limitation to an extended mission is the propellant used to fine-tune the trajectory and orient the spacecraft. A very conservative analysis has shown that not enough propellant would remain to complete even one orbit beyond the nominal mission. However, experience has shown that spacecraft perform better than conservative analysis projects — and, in fact, any of the three extended missions could be flown.

But in looking forward to an extended mission, we shouldn’t forget that the primary mission — the first 20 months that Galileo orbits Jupiter — will be a time of incredible excitement. We’ll sample the very stuff of Jupiter with Galileo’s Probe. With the Orbiter, we’ll monitor a giant planet and its satellites for nearly two years. Until now, we’ve just glimpsed Jupiter, Io, Europa, Ganymede, and Callisto as our spacecraft sped past — this time we’re going to stick around for a good look. And with Galileo, as with Voyager, the greatest discoveries will be things we haven’t even thought of.

Clayne Yeates works at JPL as Science Manager for Project Galileo. He has overall responsibility to insure that the science objectives of the mission are met, and that the mission design can support the science objectives. Theodore Clarke is the Chief of Science Integration. He will insure that the instruments aboard Galileo achieve the mission’s science objectives.



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ASTRONOMY FORUM

Bart Bok At 75

IN THE BEGINNING, THERE WAS NO BOK. And the Milky Way was without form, and void. But darkness is no longer upon the face of the deep — for the new fifth edition of *The Milky Way* is ready.

April 28, 1981: Bart J. Bok's 75th birthday. And the new edition of the book is out, making "now" a happy time in his long and rewarding life. His career, marked by professional devotion, still sparkles with the enthusiasm of a man who has lived among the stars of the Milky Way. "I started out as an amateur and after years as a professional I feel happy to be, so to speak, an amateur once again."

I first met Bart Bok when a friend requested I interview him. I arrived with my friend's impressive list of questions, which began thus:

"Twenty years ago you were in Canberra, Australia, and you began *The Astronomer's Universe* with these five words: 'Astronomy is on the move.' How would you react to those words after two decades?"

I never got to ask another question. After an hour I had to rush outside to get an extra tape so Bart Bok could fill that one as well with his incisive comments on the development of astrophysical research, the refinement of telescope technology, the role of the amateur and the planetarium in education. I remember the great excitement he showed, especially about the Space Telescope. "This is where astronomy is moving now. The direction toward larger ground-based mirrors should be altered to join the real thrust into space."

"And there will be more than one. Remember when the two-hundred inch was opened — the only one in its class? Now we have a whole

family of telescopes that approach its size and exceed its performance. When the results start showing us the enormous value of the first Space Telescope, we will build more."

Bart Jan Bok was born in Hoorn, Holland. His professional experience began as an assistant in astronomy at Groningen University while he was working on his Ph.D. there. Immediately after that, his career bloomed. 1929: Wilson Fellow in



astronomy at Harvard. 1933: Assistant Professor of Astronomy at Harvard. 1946: Associate Director, Harvard College Observatory. 1957: Professor of Astronomy, Australian National University; Director, Mount Stromlo Observatory. 1966: Head of the Department of Astronomy and Director of Steward Observatory, University of Arizona.

Impressive? But this is not all of Bart Bok — not as I know him. What about his research — on the Southern Milky Way, on star formation, on the spiral structure of our Galaxy?

But this is still only a partial list. What about his commitment, that force that pushes astronomy beyond science and into a new role as one of the central concerns of our species? There is a big difference between Bok and the scientist who devotes his professional life to research and teaching but leaves the public with little benefit of the results.

Bok is different. At a time when astrology was considered an off-limits subject, Bok helped persuade the scientific community to take a stand. The public, he felt, had the right and the responsibility to know the difference between the science of the universe and the charlatan practices of the "astro-muddlers."

What kind of man would develop into someone so caring about the world perception of science? Perhaps someone who, in 1918, joined the Boy Scouts and was confronted by a scoutmaster with a fetish for constellations. He considered knowledge of the constellations an absolute must, and Bok just *had* to sit down and learn them.

There also was Harlow Shapley, a man whom Bok respected while in high school, and with whom he developed a fine professional relationship during the years they shared at Harvard. "One requirement of a member of the National Academy of Sciences is to complete a biographical memoir about another member who has died. They asked me to do the one on Shapley." In this memoir Bok shows his strong feelings in favor of clear scientific writing in a subject that could appeal to anyone: "I wish that every scientist would read the Shapley papers in the Mount Wilson *Contributions*. They make for remarkably easy reading. Every one of them is simple and

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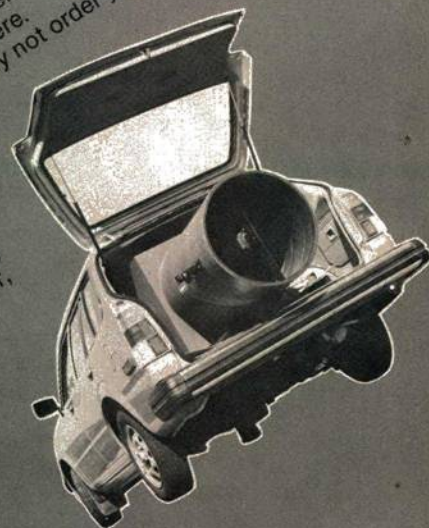
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straightforward, and they can be read with ease by any student in a beginning course in astronomy, including those without any knowledge of calculus or modern physics."

Bok considered Harlow Shapley a man of great intellectual strength and who, as Director of HCO, offered his staff freedom in their research. Bok's opinion of Shapley is well expressed by his brief critique of Shapley's volume of informal reminiscences entitled *Through Rugged Ways to the Stars*: "It is not the very best of autobiographies, but it does show the true Harlow Shapley with all his wonderful ideals, his vanity, his compassion, and his greatness."

In 1928 Bok attended the Leiden meeting of the International Astronomical Union. He and some of the other young astronomers had been asked to form a welcoming

Priscilla was intimately involved in all of the research he did both at Kitt Peak and at Cerro Tololo.

Priscilla died on Wednesday, November 19, 1975. Just four days earlier, she and Bart attended a symposium at the newly opened Flandrau Planetarium in Tucson. The seats in Flandrau's Theater had been arranged for lectures as well as for star presentations, and the Boks sat very close to the lecture stage. After the opening talk, Bart suggested that they remain for coffee and discussion but Priscilla was not well and wanted to go home. Soon after her death Bart received a call from the Planetarium: Could he drop by? In the ceremony that followed, Bart was shown a small plaque that had been placed on what was now to be known as the Priscilla Bok chair, in honor and loving memory of Priscilla's first and last visit to Tucson's Planetarium: "Priscilla F.

grandchildren were between 13 and 18 years of age. That is the primary group for whom I want to write the book — for boys and girls who have had a little physics and some simple math in high school or who are still in school and want to know about the Milky Way. That's the way I got started, and that should be the age for which it is aimed. It has to be a little tough. That's good for kids: our grandchildren had to work at it and I think they profited from it in the long run.

"Condition Two: it must be a good book for astronomy graduate students who come out of physics to enter astronomy and who want to get a feeling for what the hell is cooking in Milky Way research. Once we catch both the beginning devotees and the graduate students then we have a basis for going ahead.

"Then there are the interested and informed amateurs. With a little effort the amateurs should be able to go through it and enjoy it. But most of all, *The Milky Way* is not a textbook. There are 56 textbooks on astronomy now. I have no desire to write number 57."

"Priscilla had yet another condition: 'Bart, don't increase the number of illustrations — increase the quality. For every one you put in, throw an old one out. And don't increase the length of the book or make it more difficult. If you want to write a book to impress astronomers about how much you know about the Milky Way, do it. But take my name off — I don't belong there. The next edition could be fifteen, maybe twenty pages longer, but the book otherwise will get too fat, too costly, and frightening to people.'"

Such are the philosophies of Priscilla and Bart Bok. Even as they push our knowledge out to the stars, they keep their public with them all the time.

Bart Bok is as enthusiastic about informing people about the Milky Way as he is about his own research on it. "Scientists have a role in public education that cannot be filled only by planetarium people. An astronomer is involved every day with his own research and he knows its developments intimately. The public — and that includes children — ought to be able to share this with him."

We followed this point further. Astronomy educators have an important role, but one that is more generalized. Their job, he believes, is to alert people to the existence of a universe out there. But this must be augmented by working astronomers who paint the details, and use all the

This image shows a dark globule with a bright rim, and two Herbig-Haro objects.



Photo by Bart Bok with the Cerro Tololo 4-meter reflector.

committee — it was Bart's assignment to welcome delegates at the train station. One delegate Bok met was a young astronomer from Smith College in Massachusetts named Priscilla Fairfield. IAU meetings, then as now, last about ten days, apparently adequate time for Bart and Priscilla to become well acquainted and for Bart to say at the end that he was in love with her and wanted to marry her. A year later, Priscilla and Bart were married in Troy, New York.

Priscilla was a great astronomer in her own right. In addition to co-authoring four editions of *The Milky Way* with Bart, she worked with her husband on problems of the southern part of the Galaxy. While Bart was Director of Stromlo in the late '50s, Priscilla collaborated with him on the photoelectric data they obtained on the Magellanic Clouds. And by the time Bart became Director of Steward Observatory,

Bok, November 15, 1975."

Bart does not keep his feelings of Priscilla to himself. I have heard him give five public lectures — and in each one he has some comment to make about Priscilla and her interest in the Milky Way. "This is the Eta Carinae Nebula," he would point out, "and it is Priscilla's favorite. (pause) I miss Priscilla; I miss her very much. Before she died she said, 'Bart, after I'm gone I want to be up there in the Eta Carinae Nebula.' (looking at the slide) I suppose that's just where she is! Of course, I don't think I'll be able to join her there — I'm likely going another way!"

The fifth edition of *The Milky Way*, like the others before it, bears the names both of Bart and Priscilla. "Priscilla gave me firm instructions," said Bart, "as to what conditions her name could remain attached to the book. She sat on the sofa, right over there, and said: 'Condition One: We wrote the fourth edition when our

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(Bill's astrophotographs appear regularly in SKY AND TELESCOPE and ASTRONOMY.)



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excitement of first-hand intimacy with their subject.

Bok's own lecturing is extensive. Even while he was director of Mount Stromlo Observatory, he spoke in schools and gave public lectures about astronomy. Now, in Arizona, he has spoken before such diverse groups as astronomy club members and prisoners.

And he takes his lectures as seriously as his professional work. I invited him to a dinner in his honor before a lecture for our club. "Oh no, not tonight. Never before a presentation. I have to check everything so that the material is just right."

So there you have it: a scientist who is as intimate with the Milky Way as you are with the rooms of your house still has to do his homework!

But no ordinary homework. This is done by a scientist who has the intimacy of a long acquaintance with the sky. His doctoral thesis on the Eta Carinae Nebula was a good start, notwithstanding Shapley's "suggested" title of *Miscellaneous Nonsense Vaguely Related to the Eta Carinae Nebula*.

Then there was the 1934 *Harvard College Observatory Bulletin* that took issue with Hubble's suggestion that galaxies are distributed evenly in space. Bok suspected that galaxies cluster — Hubble's evidence even pointed to it. But over three years later, Hubble still wouldn't talk to Bok!

And of course, the spiral arms. Working out their positions and nature was Bok's central concern for many years. In 1959 he suggested a possible Carina-Cygnus arm — an arm you can almost see as it stretches across Carina, right through us, and on to Cygnus. It was a thought he got while staring at the Milky Way during a Panama Canal passage. Is this really science? A romantic thought about a hitherto undetected arm that you just look up at and see?

Of course. It is the undefined — and often ignored — first step of a long process of scientific inquiry. The Carina-Cygnus idea took off on a trip of its own, and landed in the first edition of *The Milky Way*. But it hasn't survived. There is a spiral feature in Carina, as there is in Cygnus, but the connection doesn't spiral out through us.

"BART J. BOK, A.A., O.A.P." The postman wants to know what the initials stand for. "After all, you are a great astronomer, and these letters must refer to some major honor you have received."

"Oh yes," says Bart Bok, "The A.A. means that I enjoy my Sherry, and the O.A.P. means that since I've retired, I am an old age pensioner with no income worth speaking of!"

But A.A., O.A.P. do mean something else: they tell of the search for the spiral structure of the Galaxy, of Bok globules. They involve the sensitivity and enormous compassion of a man with a concern for the condition of humanity. They salute public lectures as a professional responsibility deeply felt, recall the expression of a boy wild with excitement at a show-and-tell session of school, and tell of the wisdom that comes from decades of respect for his subject.

Last summer, Bart Bok saw the total eclipse. I envy those who went with him. What memory will they treasure more — totality in nature or the chance to hear Bok speak?

I've seen an eclipse and I've heard Bok. I am fond of both memories. Bok the comedian. Bok the thoughtful raconteur. Bok in favor of a future with a Space telescope. Bok who loves to rise at five to be the first to see Venus in the morning sky. Bok the astronomer who will speak longingly of Priscilla. And Bok, who at age 75, appears to be still at the forefront of his field. Yet all this does not give the totality of Bok.

— David Levy
Tucson, Arizona

Are the Soviets Ahead in Space?

Comparing the Soviet and American space programs is like comparing apples and oranges. The closer you look, the greater the differences become. Generalized comparisons lose significance. Divergences in program emphasis, hardware design, operational philosophies and environmental constraints all tend to cloud comparisons both of the programs as a whole, and of specific systems such as the Space Shuttle.

At first glance, the Soviets seem to have a commanding lead in space. From November 1979 to November 1980, they launched 99 satellites weighing a total of 350 tons. In the same period America launched only 14 satellites — a mere 44 tons total.

But this lead evaporates upon close examination. Of the Soviet satellites, some 60% of their total payload to orbit, or 37 satellites, were military reconnaissance flights. For the most part, these were simply unmanned versions of the Vostok spacecraft which orbit for two weeks and then return to Earth. America's military reconnaissance needs were met with only two launches of the sophisticated Big Bird satellite, which accounted for 70% of our total payload to orbit weight. Another 16 of the Soviet launches were small military communications satellites. American military communications needs were met by just three launches. There is little reason to believe that America trails the Soviets in these fields, numerical comparisons notwithstanding.

The Soviet space program consists primarily of a large number of simple satellites launched into low Earth orbits. The American space effort is characterized by a much smaller number of much more

sophisticated satellites in high Earth orbit. Less than a third of Soviet satellites have orbits higher than 800 km, while over two-thirds of American satellites orbit higher.

This is due, in part, to geography. The Soviet Union's launch sites lie far to the north of American launch sites. Thus, the equatorial geosynchronous orbits preferred by America are difficult for the Soviets to achieve. Instead, they place a larger number of satellites in lower orbits to perform the same mission. Quantity is stressed over quality, and low cost over reliability. The average operating life of Soviet satellites is a little less than two years, while comparable American vehicles have typical operating lives of five to seven years. The consequent need for frequent replacement of malfunctioning satellites increases the number of Soviet launches without increasing their results as compared to the United States.

The diversity of Soviet man-related spacecraft is also less than it would seem at first glance. The Progress cargo transport is essentially an unmanned version of the Soyuz manned spacecraft which the Soviets have flown in various versions for over a decade. The Soviet shuttle will replace these vehicles, rather than operate in conjunction with them. The American counterpart of the Soyuz/Progress/Shuttle/Salyut system is the Shuttle/Spacelab combination, which does not suffer by comparison.

American space expenditures include about \$5.4 billion by NASA, \$7.5 billion by the Defense Department and other national security agencies, and several hundred million dollars by other sources — almost \$14 billion per



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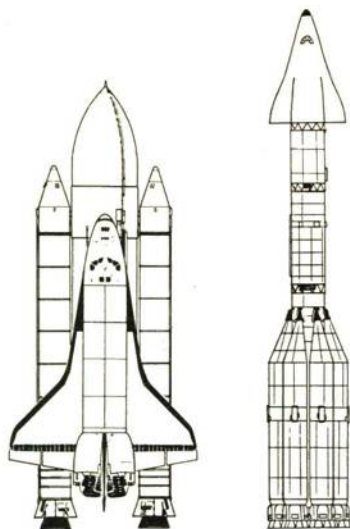
Although no budget figures are available, analysts believe the Soviets devote a much higher proportion of their GNP to space than does America. Of course, since the American GNP is twice that of the Soviet Union, the Soviets must try twice as hard just to keep up. And the Soviets also devote a much larger share of their GNP to agriculture than does America. If GNP comparisons were meaningful, we would expect the Soviets to flood us with their wheat, which they obviously do not.

A number of things indicate that the Soviet space program faces very real budgetary constraints. After 25 years, they continue to use the same booster that launched Sputnik 1. Their standard military reconnaissance satellite is of similar vintage. These simple vehicles have been mass-produced by the hundreds to reduce their unit cost — a technological stagnation that suggests limited funds for expensive research and development efforts.

In addition, the Soviets have refused Bulgaria's request to fly another cosmonaut to the Salyut space station — an effort that would soften the failure of the first Bulgarian attempt to dock with Salyut. An additional unmanned launch has been offered instead. Early in 1981, it was announced that the joint Franco-Soviet 1984 Venus mission would be substantially reduced in size and scope. And recent Soviet statements on space have been notably defensive about the cost of these endeavors.

Sometime in the next year or two, the Soviets will launch a new space vehicle, a reusable space shuttle called the Albatros, also known as the "Raketoplan" — rocketplane, or "Kosmolyot" — spacecraft. Development of the Albatros began in the early 1970s, relying in part on American work on the Shuttle. A prototype was drop-tested from an airplane in 1975, and orbital re-entry tests were conducted in 1976, 1978, and 1979. A landing runway at the Tyuratam cosmodrome has been under construction for several years.

The Albatros will be used to support the large space station the Soviets are expected to orbit within the next few years. The high number of expendable Soyuz/Progress flights required to support the Salyut space station precluded the use of sophisticated equipment, and led to several mission failures. More extensive space station operations will require many more flights and a much higher level of reliability. The reusable Albatros is a response to



this requirement.

Although the Soviets have released little technical information on the Albatros, there seems to be a consensus in the West that the vehicle will be about 15 meters long and have a wingspan of about 10 meters. Total weight will be about 20 tons, with a payload of 2 to 4 tons, including a crew of two and several passengers.

Initially the Albatros will be launched by the same D-class booster that orbited the Salyut space station. This launch vehicle was used in the three re-entry tests conducted in the 1970s. The Soviets have long had a serious reliability problem with this booster and "man-rating" it may prove to be a difficult task.

There has been considerable speculation about a possible follow-on horizontal takeoff air-breathing booster for the Albatros. This speculation has been fueled by statements from various Soviet authorities. As yet there seems to be no firm commitment to such an option, and good reason to believe that no such booster will emerge.

The Albatros, as configured for launch atop a D-class booster, is unsuited as an upper stage for a horizontal takeoff booster. The Albatros itself is too small to have any significant on-board propulsion capability. Western studies of such a launch vehicle suggested the need for an intermediate non-recoverable second stage to place the shuttle in orbit after release from the air-breathing booster. Such an arrangement is complicated and costly.

Configurations of this sort were widely studied in America and in Europe during the 1960s. Of all the various booster combinations considered, it had the lowest payload and highest development

and operating costs. Such configurations were dropped from consideration for the American Shuttle for good reasons. Given the technological and budgetary constraints facing the Soviets, a similar conclusion can be expected.

The operational flexibility of such a system is also less than it could be. Only seven airstrips in the world are capable of handling an American Shuttle landing — and a large convoy of support vehicles is required to support each landing. Similar limits would apply to the Albatros. To say that the Albatros and its air-breathing booster could operate from any airfield in the Soviet Union is to seriously underestimate the magnitude of the task.

The military advantages of such operations are unclear, since it is difficult to imagine plausible scenarios which would deprive America of both Kennedy and Vandenberg launch facilities, and at the same time leave Albatros-rated airfields in the Soviet Union unscathed. A far more dependable way to deploy satellites in wartime is on ICBMs launched from hardened silos. The Soviet F-class booster, which is based on the SS-9 ICBM, is such a system. In America, proposals to use Poseidon or Trident missiles as satellite boosters have received some attention.

The U.S. Air Force finally concluded that the direct military utility of a small spacecraft such as the Dyna-soar — an Albatros-like vehicle — is minimal. There is little reason to believe that the Soviets will be able to escape a similar conclusion.

As America moves into the shuttle era, the Soviets will continue to rely on expendable boosters for most of their space activities. Although the Albatros will make a major contribution to the Soviet space effort, it is no match for the Shuttle. By 1983, the planned level of Shuttle flights will dwarf the Soviet operation. Unless the Reagan Administration foolishly curtails our space program, the 1980s will be the American Decade in space.

— John Pike
Atlanta, Georgia

John Pike is a member of the National Committee of Citizens for Space Demilitarization. He feels that Donald Robertson's analysis of the Soviet Shuttle (*Astronomy*, April 1980) is "marred by factual errors and technically unsupportable interpretations," and that "propping up a Soviet straw man will contribute little to our own space program or to international peace."

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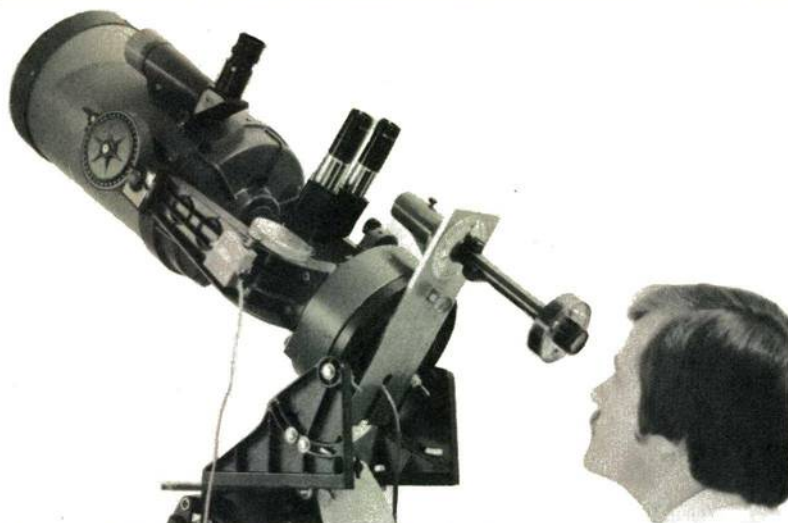
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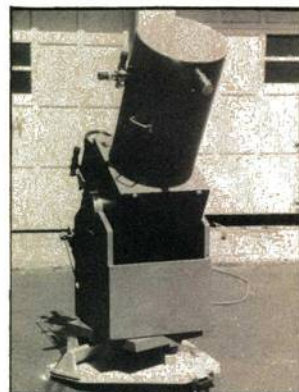
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eye on the sky

alignment of bright planets begins

by Fred Schaaf

the wanderers

If you stay up late this month, you'll see a brilliant line of planets begin to form across the southern sky as **Mars**, **Jupiter** and **Saturn** come to opposition within four weeks of each other. Watch closely as these bright wanderers apparently come to a halt and then begin retrograde (westward) motion among the stars. All of the planets except Uranus and Neptune will be stationary in right ascension sometime during February.

Although **Mars** is often the dimmest of the classical planets, its brightness increases dramatically for one long season every second year. This month we begin the early stage of that season. The planet brightens noticeably from week to week as Earth approaches it. By the end of February, it will shine enough to draw the attention of even a casual observer, and it will quickly outshine Capella and Arcturus. Compare it to these two stars each week and you'll notice its gains in magnitude.

After it begins retrograde motion on the 21st, Mars will head back for an encore of its January conjunction with the star Gamma Virginis. This meeting will be much closer and more spectacular than the first, since Mars will be brighter than it was last month.

Saturn rises soon after Mars, and it will also be involved in a repeat of a January conjunction. The ringed planet starts retrograding on February 1, and approaches slightly more than 5° due north of first magnitude Spica on February 25. Saturn will shine at +0.7 magnitude for this conjunction.

You won't have to wait much later to see a third planet follow Mars, Saturn and Spica. **Jupiter** will blaze brighter than Sirius, all alone in dim Libra. This gas giant begins to retrograde on the 24th — just three days after Mars.

Mars and Jupiter will not be close to each other for as many months as they

were in 1980. Even though Mars draws close to Saturn this month, it will start to retrograde away before they can have a conjunction. But what will happen in these next few months?

Mercury is visible in the pre-dawn sky later this month, as it pulls out to greatest western elongation (26.9°) on the 26th. Northern hemisphere observers won't see much at this apparition, because the tilt of elongation is not inclined steeply to the horizon. **Venus**, too, has an unfavorable apparition for North American observers, but that planet's brightness will make up for its poor positioning. Dazzling Venus underwent inferior conjunction on the 20th and moves so fast — because it is so close to us — that it even stays ahead of the innermost planet. Venus races toward its own greatest western elongation on April 1.

On the 25th, Venus brightens to magnitude -4.3. This month will be superb for following Venus past dawn and into the midst of day with the naked eye. It is an observing thrill to see a planet shining in the daytime sky. Many readers will be standing in snow as they watch Venus on clear, cold February mornings. If you go out before twilight — late in the month, when Venus rises early — look for your shadow as you block the bright light of Venus. I once saw an amazing sight on hard, glazed snow — a prominent pathway of light running across the field before me. It was Venus-light, shining through a break in the trees!

the starry sky

A host of splendid winter constellations now spreads across the southern sky. In this region of the heavens, you'll find many of the brightest stars, and a mixture of young and old stars. Our survey across this realm takes us from one bright young star cluster to another which is very old.

Let's begin our night's tour on the western bounds of the winter constellations where the charming **Pleiades** star cluster floats. Long-exposure photographs show these young stars still swathed in the dusty nebulosity which gave them birth — a very recent event on a cosmic scale. Small telescopes in dark skies often show traces of this nebulosity, especially near **Merope**, and several famous observers have made the fascinating point that the naked eye — a very "fast" instrument — may be able to glimpse hints of the Pleiades nebulosity. The cluster's multiple twinkling, however, makes this very difficult. Its interplay of twinklings rather than its nebulosity probably inspired Tennyson to write of watching these stars "glitter like a swarm of fireflies tangled in a silver braid."

How recently were the Pleiades born? Probably about 50 million years ago. If that seems like a long time, consider Walter Scott Houston's comment that the Pleiades were probably never seen by the dinosaurs, because the animals died out at just about that time. Those mighty rulers of Earth never got to see the Seven Sisters — but the first flowers of Earth sprouted up to greet the Pleiades, which were also breaking out into light.

To the southeast of the Pleiades, the much older **Hyades** cluster surrounds bright **Aldebaran**, the eye of the bull, but those stars are really much farther away than Aldebaran. All are part of **Taurus** the bull, whose horns extend to a meeting place of Taurus and several

Above: A thunderstorm provides atmospheric fireworks above Flagstaff, Ariz. Photo by Charles Capen. **Below:** Venus, Jupiter, and Saturn join the crescent Moon during evening twilight. Mr. and Mrs. David Dundore captured this conjunction with a 135mm f/3.8 lens and a 2-second exposure on ASA 400 film.



star dome

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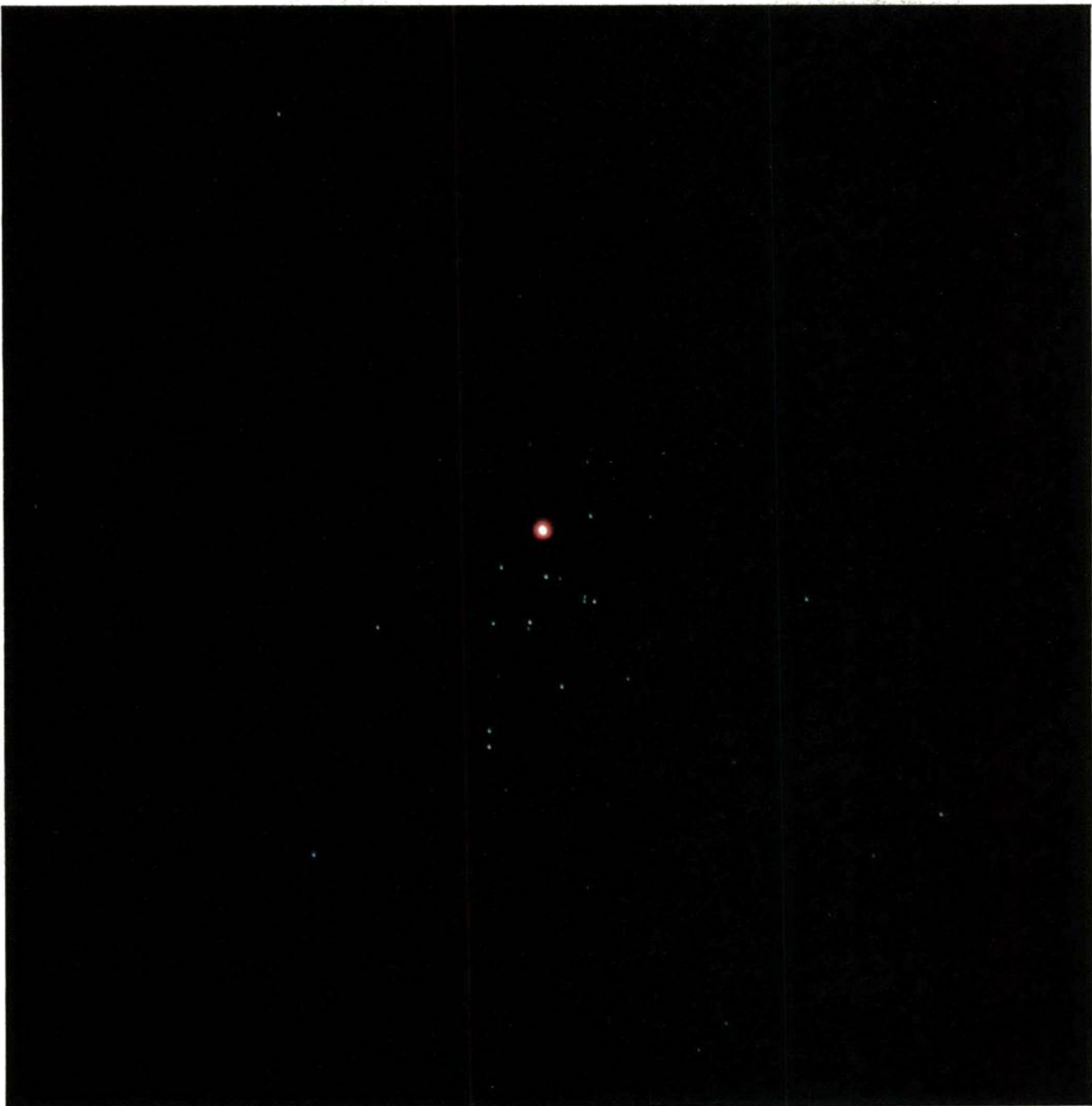
9:30 p.m. on February 1
8:30 p.m. on February 15
7:30 p.m. on February 28



february sky almanac



- 1st** First Quarter Moon is at 9:28 a.m. EST.
- 5th** The Moon is closest to Earth (perigee) this morning: 226,863 miles.
- 8th** Full Moon comes at 2:57 a.m. EST.
- 12th** Look for the Moon near Mars and Saturn in the pre-dawn hours today. After sunrise, it will pass north of Mars (around 11 a.m. EST) and Saturn (around 5 p.m. EST).
- 14th** At about 5 a.m. EST, the Moon will pass 4° north of Jupiter. Look for the pair close together after midnight.
- 15th** Last Quarter Moon is at 3:21 p.m. EST. Each morning, from now until about the 23rd, Mercury will be at its most visible for this apparition. Look for it an hour before sunrise about 5° above the horizon in the east-southeast, below and to the left of Venus.
- 17th** The Moon is farthest from Earth (apogee) this morning: 251,345 miles.
- 20th** A waning crescent Moon will lie directly north of Venus at 11 a.m. EST.
- 23rd** The Moon is New at 4:13 p.m. EST.
- 25th** This morning, Venus shines at -4.3 magnitude — its greatest brilliancy for this year. If the ground is snow-covered, look for your shadow where you block the planet's light.
- 26th** Mercury is at greatest western elongation and lies 27° west of the Sun.



Several of the bright naked-eye planets have traversed M-44, the Beehive cluster, in recent months. Robert Zaas photographed this close approach of Mars with a 400mm lens, tracking the cluster on August 31, 1981 and recording the striking passage with a five-minute exposure on ASA 400 film.

other major constellations. This location is home to the summer solstice, and one of the two junctions of the ecliptic and the galactic equator — the midline for the Milky Way band of luminosity. Also close to this spot is the point in the heavens directly opposite our Galaxy's center.

Above this great intersection is **Auriga** the charioteer. Although it features bright Capella, Auriga also includes Epsilon (ϵ), a very luminous

star, even though it is dimmed by such a great distance.

South of the meeting place is **Orion** the hunter, blazing with most of the brightest stars in our winter sky. **Betelgeuse**, in his right shoulder, is a red giant, older than the upstart blue giants that are so numerous in Orion. Blue giants like **Rigel**, at his left knee, are such energy spendthrifts they will reach the red giant stage very quickly. Our not too distant descendants may see a red star where we once saw blue Rigel.

East of the summer solstice point is the 5th magnitude open cluster **M-35**, which lies at one foot of **Gemini** the twins. The constellation's two bright stars, **Castor** and **Pollux**, are only 0.4 magnitude apart in apparent

brightness, but are even closer in luminosity. Pollux is 35 times the Sun in true brightness, Castor about 36. But Castor and Pollux are quite different: Pollux is a single sun, while the point of naked-eye light we call Castor is composed of at least six stars.

Below the twins shines **Canis Minor** the lesser dog. **Procyon** is the brightest star in the constellation, but it appears bright mainly because it lies very close to Earth. Canis Minor will be the apparent point of origin for Comet Halley, which will reach perihelion four years from this month.

The winter **Milky Way** turns brighter as it runs southward between Canis Minor and **Canis Major**, pouring across the constellations **Monoceros** and **Puppis** with several clusters in

naked-eye or binocular range. But it's difficult to take your eyes off the brilliant glow in the big dog — **Sirius**, the brightest star in the heavens.

Sirius is the most luminous sun within our immediate stellar neighborhood, but within its own constellation there are more distant stars thousands of times intrinsically brighter than Sirius. **Wezen** and **Aludra** [(Delta (δ) and Eta (η))] are as radiant as Rigel and even farther away. These stars form a triangle with **Adhara** [Epsilon (ϵ)] which would be famous as a great asterism if it were not out-dazzled by Sirius. Adhara has an apparent magnitude of 1.5 — almost as bright as Regulus and brighter than Castor!

We end our month's survey with a bright cluster — one that is very old: **M-44**, the **Beehive**, in dim **Cancer**. It is visible with the naked eye.

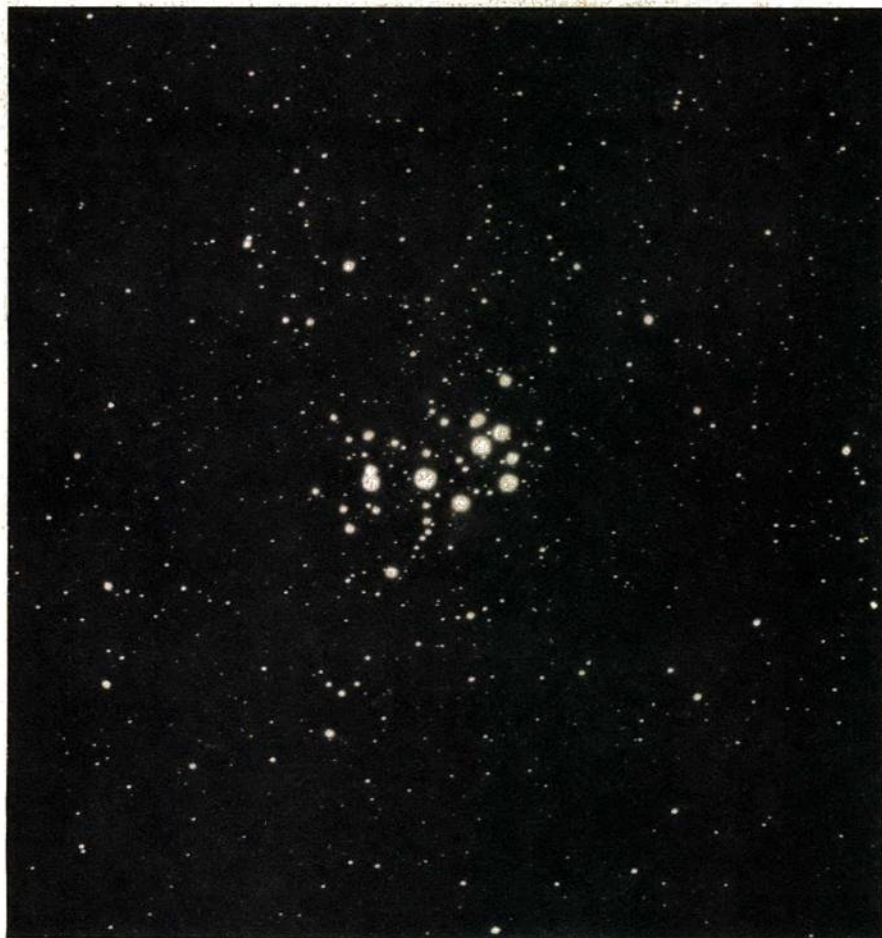
skylore

Last month we explored the many roles of Sirius in Egyptian mythology, and the name itself, which is very old. But Sirius-lore is present in every corner of our world and some of the legends and ancient observations have even attracted the attention of modern astronomers who want to learn more about the fascinating Sirian system.

We derive the expression "dog days" from the Dog Star, Sirius. This term was applied even before the time of Christ to scorchingly hot days of summer. Since Sirius was near the Sun at this time of year people thought it was adding its heat to the Sun's. Not all of the classical writers regarded Sirius as having only unfortunate effects. Pliny thought that Sirius was the most important source of honey, which he believed to be the sweat of heaven or the spittle of stars. According to him, Sirius had a "sweet influence" on the Earth.

We have very little information about the star legends of the Norsemen, but according to one researcher, Sirius was the giant Thjazi who kidnapped Idun and the apples of eternal youth which she gave to the gods. This claim does not seem supported by translators of *The Eddas*, compilations of Norse mythology. According to those scholars, after the gods killed Thjazi, Thor compensated the giant's sister by tossing her dead brother's eyes into the heavens where they became stars. However, we do not know which two stars are "Thjazi's Eyes." They might be Sirius and Procyon, but more likely they are Castor and Pollux.

R.H. Allen says that the Norse knew Sirius as the dog Greip — Sirius was canine or lupine in many widely separated cultures. The Chinese knew



Pleiades

Ewell Schirmer

it as their Heavenly Wolf, and for some American Indians Sirius was one of the two dogs that guarded the Path of Souls, the Milky Way. The spirits of the newly dead had to first cross a narrow bridge spanning a torrent of oblivion into which all cowards fell.

The brave souls who managed the perilous crossing then had to walk the length of the Milky Way. Each end was guarded by a dog that the souls would have to appease with food in order to pass. The second dog was the star Antares at the summer end of the Milky Way; the first was the dog Gili — our Sirius.

Sirius was supposedly called Hannabeah, "the Barker," by the Phoenicians, but in other lands Sirius was not known as dog or wolf. In the South Pacific, our dog star was Mere who helped pursue the sky's only brighter star. The god Tane broke this star apart because it had been too vain, and its pieces now make up the Pleiades.

A Finnish poet, Zakris Topelius, said that Sirius was so bright because it was the blending of two lovers, Zulamith the Bold, and Salami the Fair. These lovers labored for a thousand years to build a bridge so they could be together — the Milky Way. Once finished, they "rushed into each other's arms and melted into one,"

becoming the brightest star.

One of the Arabic names for Sirius was Barakish, "Of a Thousand Colors," a reference to the star's prominent and exceedingly beautiful colors in scintillation. Another Arabic title for Sirius was Al-abur, who was the twin sister of Al Ghumaisha (Procyon) until their brother Suhail (Canopus) murdered his bride (possibly Rigel). According to this story, Al-abur was both ashamed and angry, and chased the brother, who fled far to the south.

Sirius was various figures to the Hindus over the centuries. It was Sarama, messenger of Indra and herdsman of the sky's cows — the clouds. Sarama takes the form of a greyhound to aid people lost in dark places. But later, Sirius, or all of Canis Major, was the Deer-slayer or the Hunter, who shot Praja-pati (lord of light, our Orion) when Praja-pati in deer form chased his own daughter Rohini (Aldebaran) who was fleeing as an antelope. We can still see the Deer-slayer's arrow stuck right through Praja-pati — it is the Belt of Orion.

The Greeks had many myths of dogs that are sometimes associated with Sirius. People on the isle of Ceos especially worshipped the star, and classical writers including Homer and Hesiod often refer to it. Sirius is Homer's "Star of Autumn."

ASTRONOMY IN FOCUS

Letter to the President

Sir/Can you believe these budget cuts? It's ridiculous! There is nothing left for the Voyager 2/Uranus encounter. I wrote to the President and I've enclosed a copy of the letter I sent him. I am also sending letters to Senators, including Wisconsin's William Proxmire, who is highly against the space program, and to various subcommittees.

Kevin Righter
Murrysville, PA

Editor's note: Here is the text of Mr. Righter's letter to the President:

Dear Mr. President,

How many new worlds have been discovered in the recent Voyager missions to Jupiter and Saturn? I have counted 20+ not including Saturn's huge ring system and the discovery of the minuteness of our planet on the universal scale.

Being sixteen years old, I had figured that I would take part in the discovery and exploration of our solar system, whether it be through manned or unmanned missions, after my schooling. I wondered what it would be like to have all of the Voyager pictures and information available to me, or to work with other people in sending a man to the Moon or launching a probe to the planets. The Pioneer and Voyager missions were so spectacular that I could not ignore them (as many people did for some reason). I instantly became interested and read everything I could to prepare myself to enter this field of study.

My ultimate goal is to join NASA and help our nation and world to expand into the infinite universe. BUT with recent setbacks and delays in our country's Space Shuttle program, and the almost total

elimination of our deep-space program, how can someone like me be encouraged to enter this field?

The Space Shuttle is having problems, because it was not funded properly during development. Too many things had to be taken for granted, and design capabilities could not be subjected to enough testing. I am sure that the Shuttle's problems will eventually work themselves out, but what about the deep-space aspect of our space program?

I have heard reports that four out of five of NASA's deep space probes for the future have been cancelled. The Halley's Comet Intercept Mission, Galileo Orbiter, Venus Orbiting Imaging Radar Probe, and the International Solar Polar Mission have all been axed by your administration. This is the heart of the U.S. space program!! There is nothing left except for the Space Telescope. The Voyager 2 encounter with Uranus is also left, but it has only a 50/50 chance of surviving. I realize that the Space Shuttle is very important to the military, and also to NASA, but space exploration is also important, and to see it wiped out within one year is devastating and depressing.

I am sure that there are thousands of students my age who feel the same way as I do. What are we to do now? Should we change our interests now, or should we assume that the budget cuts are only talk? What will happen to JPL and all of the other NASA dependent organizations? Won't the military suffer without NASA's technology received from space exploration?

I think that a rebirth in the country's space exploration program would: 1) contribute to the military's technology, 2) help bring the struggling economy back to life, 3) bring technology and breakthroughs

to the public, 4) stimulate national spirit and confidence, and most important, 5) push mankind into a future of exploration, discovery and prosperity.

Kevin Righter
Murrysville, PA

Space and The Military

Sir/I'm new to the astronomy field, and as I have the good fortune of sharing this splendid continent with you — north of Niagara Falls — perhaps you will allow me to conduct a somewhat naive, impartial discussion of Rep. Larry P. McDonald's comments in the November issue of ASTRONOMY.

The Congressman from Georgia suggests that NASA projects without "direct military applications" should be jettisoned because they "do not withstand constitutional scrutiny."

Without dwelling on the Congressman's shameful manipulation of (by?) high-powered military contractors, can we infer from his comments that he believes the increasing production of sophisticated weaponry is constitutionally defensible whereas space exploration is not?

Jon W. Kieran
Toronto, Earth

Space and Hunger

Sir/Too many people, like Eric Carleen (In Focus, December 1981), have been brainwashed into believing that space operations cause hunger on Earth. The reverse is true.

Not one crumb of bread, or drop of milk have been sent to the outer planets. People have earned decent livings for their families by building and operating the spacecraft. Such activities have lasting social value far beyond "digging holes and filling them up again" as suggested by men

of finance to keep our supposed excess labor force out of mischief.

Thomas Ross
Seattle, WA

Jobs Through Space

Sir/ In ASTRONOMY's December 1981 In Focus, Eric Carleen compares the Viking Fund with several social programs. I'm sure Mr. Carleen knows that the fund appeals for donations from private citizens and not from the government. The other programs he mentions are funded by tax dollars — quite a difference.

The money raised by the Viking Fund is not put on a spacecraft headed toward Mars. Instead, it goes to paychecks of workers at the Jet Propulsion Laboratory. The workers need the money to pay for food for themselves and their families. Those people who donate to the Viking Fund help these workers keep their jobs. So in reality the Viking Fund actually is one of Mr. Carleen's so-called "mundane jobs program."

NASA, besides employing thousands of workers, provides business for several hundred companies throughout the entire United States.

There are many such companies in my part of the country. The most prominent, the Rocketdyne Division of Rockwell International, is located within one-half mile of my house. This company built the engines for the Saturn V rocket and currently produces the engines for the Space Shuttle program. And this is just one company; many others directly or indirectly produce equipment for the NASA program.

It's obvious that the money brought in by NASA and the Viking Fund has a lasting impact on jobs and the economy.

Timothy R. Williams
Canoga Park, CA

Starting an AstroClub

Sir/We are greatly indebted to you for your article about forming an astronomy club (October 1981). It helped us to organize our publicity, sign up members, and just plain "get our act together." The article was well written, concise, and packed full of ideas.

The DHSAA started as an idea last school year when, after attempting to get an astronomy class for this year, a few students and one teacher got together for three observation sessions. Today we are at least ten strong and still growing. Our first meeting is scheduled for this Thursday, and we know it will be a success.

Thank you again for your help and your magazine.

Dover High School
Astronomical Association
Dover, NJ

Planetary Doom

Sir/I was deeply disturbed by two things in the December 1981 ASTRONOMY — namely, the letter by Eric Carleen and the lead feature of AstroNews, both outlining doom for the planetary program.

I would be a bit more inclined to take Mr. Carleen's point seriously were it not for the following: At least a couple of large "help the people" programs lose more money to fraud than NASA spends in a year — and only a very small part of the NASA budget is spent on the planetary program. The sad fact is that Joe Public doesn't even realize this, but instead goes on believing that NASA slap-happily throws around all the money it wants to. Classmates of mine were astonished when I proved to them that Voyager had cost less than 40 cents a year per person. For the money, this is one of the greatest opportunities we have to learn about the origins of the solar system and, ultimately, ourselves.

As for patience, which Mr. Carleen suggests, I say the heck with that. I for one am not expecting (hoping, yes — but not expecting) to see Halley's Comet again in 2061, and I would like to see that probe go. If you're telling me that you can't afford your share, Mr. Carleen, (probably no more than 50 cents — two measly little quarters!), then you've undoubtedly already cancelled your subscription.

One last point: The AstroNews item mentioned that Voyager 2 might simply be shut down on the way to Uranus. For crying out loud, the thing is already out there, just begging to send back data from a world we've never directly studied. Why in the world kill it now?

The last half of the twentieth century will be remembered primarily as the time when we took a giant step. We must decide whether that step will be forward or backward.

Rick Ramsey
Englewood, OH

OOOPS!

The photo of NGC-2903 on page 103 of the December issue was taken by Lee Coombs, not Martin Germano. Our apologies.

behind
the scenes

flying the mission

This month, ASTRONOMY features the Galileo mission to Jupiter. In early December, as this is written, it appears that the White House will not support funding for this program.

Clearly, this is not the time for you to decrease your support for the space program. Continue writing letters to your Senators and Congressmen. Even if you've written before, write again. Mention the Galileo mission to Jupiter. Join pro-space groups such as the Planetary Society. Talk up your friends. Ask them to write letters, too. Get involved in letting people know about the U.S. space program.

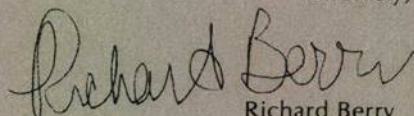
Astronomy clubs can contribute in a vital way — by spreading the word to larger groups of people. Make sure the general public knows about your meetings. Make doubly sure that radio stations and newspapers in your area know when you've got a good lecture scheduled. And keep talking about space. I know from my own experience that the Voyager pictures bring home the

idea of going to other worlds — and really appeal to people.

And for yourself, as you learn about the Galileo mission, read between the lines about "science objectives" and "achieving an orbit." Think about what it means. Put yourself out there. Pretend you're the spacecraft flying just a thousand kilometers over the pole of Ganymede. Imagine the subtle magnetic fields brushing your sensors, feel that particular deep infrared throbbing that tells of rock and water, the chill ultraviolet glow that tells of an ever-so-thin atmosphere. Look down at those odd wrinkles on the surface as you zoom past — it's a planet that once started to churn inside, then froze solid.

Maybe your friends will think you're nuts — but that's a small price to pay for the dream of space.

Sincerely,


Richard Berry
Editor

Cosmic Connections now has the largest supply of scopes and accessories in the midwest. We have in Dynamax 8, RV-6, and Dynamax 4 by Criterion, Meade 2080's, Celestron Telephoto's, C-5, C-8, C-11.

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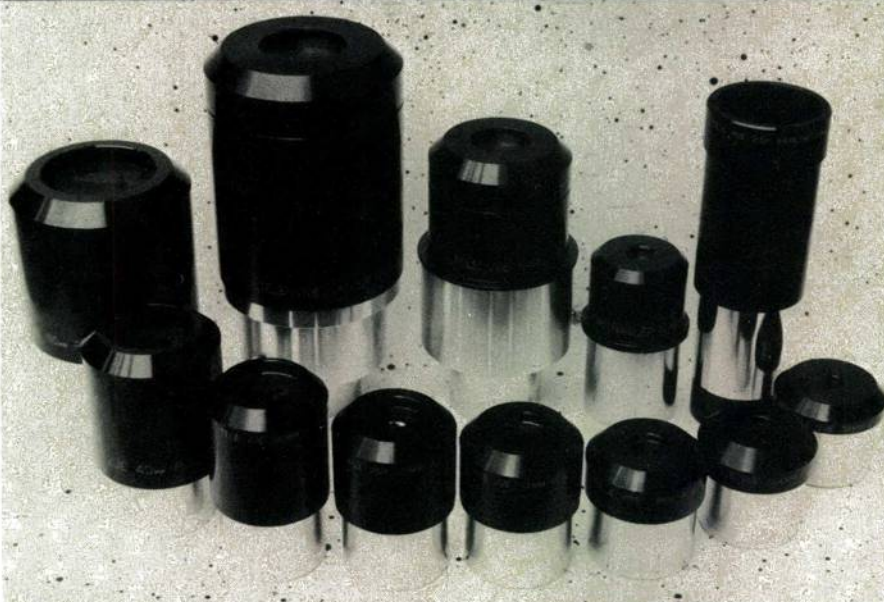
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cameras for astrophotography

Choosing the best camera to aid you in observing the heavens is one of the most perplexing equipment decisions you can make. There are so many different kinds, and deciding which one is right for you can lead to premature greying. To simplify your decision, you can use the same process that narrowed down your choice for a telescope.

Once again, identifying your specific needs is the first step in picking photographic equipment. Today observers can choose between formats, or film sizes, ranging from 110 miniatures to 8x10 monsters — and everything in between. All are commercially available and some can be made at home, but the most important consideration is the camera's compatibility with your present telescope or other equipment.

Obviously there are certain things more important than others. For instance, how would you piggyback with your 2.4-inch refractor if you decided to buy an old 8x10 press camera? Your little scope would look pretty silly sagging under the weight of a monstrous camera — and guiding would be very difficult. Beyond that, the cost of 8x10 sheet film could severely cramp your style.

Although the detail an 8x10 piece of film can record is tremendous, you had better be prepared to develop it yourself. Most commercial photo lab technicians will simply laugh when you bring in your large format film and ask them to develop it — or they will charge you accordingly. Either way you lose.

On the other extreme, you certainly don't want to waste the detail-producing power of your 30-inch Schmidt-Cassegrain by taking pictures with a "tourist-version" 110. The film size is not large enough to record the incredibly sharp detail your scope produces. Therefore you're stuck with very small images of Jupiter that you

can't enlarge because the film grain is too noticeable and makes Jupiter look like a small, blotchy blob.

Where does this leave the observer? Fortunately, you're in a better position now than in earlier years. By far the most recommended camera today is the 35mm single lens reflex (SLR). Its versatility and compact size make it the ideal choice for the vacation snapshooter or the seasoned astrophotographer. Since 35mm cameras have interchangeable lens capability, you can use them on the side of the telescope — to produce striking constellation photographs — or with the lens removed at the prime focus of the instrument to record highly magnified and detailed images of the planets and the Moon. And because of its small size and light weight, the 35mm is easy to attach to either end of your telescope.

To be fair to other types of cameras, and other observer's tastes, all sizes — from 110 to 8x10 — have both merits and drawbacks. You have to decide which one is right for you. If you think that an 8x10 is just what you need, then by all means get one. However, if you are not that deeply involved in the hobby, a smaller and more versatile camera might be a better choice. Either way, you're the one who has to use it — so satisfy yourself and shoot the kinds of pictures you like to see.

110

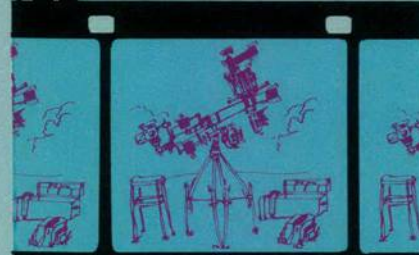


Compact Models

Today you can buy 110 cameras that have interchangeable lenses. Just a few years ago these cameras were unheard of and when you mentioned "110" you really meant "Instamatics." But even though you can now use different lenses on them, they still use 110 size film. That's their biggest drawback.

While a 110 is small and light and fits easily onto a telescope, its tiny film format precludes its use for serious photography. It's not that you *can't* take good pictures with them — you just have to realize their limitations. Some of the better 110 cameras like the Pentax or Olympus might be good for producing star trails, constellation photographs, or pictures of the Moon as seen through the eyepiece of your scope, but that's about it. You can forget about close-ups of the Moon or planets because when you enlarge the negatives a lot, even fine-grain films are too grainy.

126

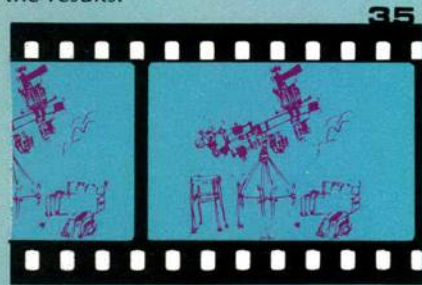


Another favorite small camera is the 126 Instamatic. Kodak made a lot of them in the 1960s and still does today although they have been replaced as the standard tourist snapshooter by the more advanced Ektalight models. If you have an old 126 up in the attic, it can serve as a good first camera to experiment with. Although they were not designed to take time exposures, they can be modified — broken actually — so that the shutter will remain in an open position. When you break the shutter remember that you will have to use the "hat-trick" method — covering and uncovering the aperture of the scope with a hat or piece of black cardboard — to get exposures. The main drawback with these cameras is that you can't change the lens — or even remove it. Usually they are supplied with a slightly wide-angle lens that is very slow by

photographic standards — f/6 to f/9 — so they are not good for piggyback photographs or even unguided tripod mounted shots.

The 126 is adequate for taking pictures through the eyepiece of a telescope, provided the object is bright — like the Moon or the Sun. Once again, since they have fixed shutter speeds, about 1/90-second, they are more or less useless for many of the objects you want to photograph. These include the planets, lunar and solar close-ups, even star fields at a long exposure. Also, 126 size film is only available in a few types. Some of the newer emulsions that are especially good for astrophotos are not supplied in 126 size — but old standbys like Tri-X and Kodacolor are still available.

Next comes the Polaroid. These cameras are also good “beginner instruments” that help teach the basics of astrophotography. The best Polaroids for astro purposes are the older Land models — not the new SX-70s or their cousins. If you have an old Polaroid, you can take time exposures with it simply by taping the shutter button down. Then if you use black-and-white film Type 667, rated at ASA 3000, you can easily take tripod mounted pictures of star trails and constellations and make piggyback guided shots. Just for the sake of experimentation, try holding the camera up to the eyepiece of your scope on the night of a first quarter Moon. You should be able to capture some kind of image. These cameras are great for beginners because their film develops instantly — although you will have to do it indoors if it's cold outside — and they are not that hard to modify for astrophotography. Give one a try — you'll probably be impressed with the results.



Sport Models

The 35mm SLR has become the standard tool of the professional photographer and the astrophotographer alike due to its limitless number of lens combinations, shutter speeds, and available film types. Originally designed to produce still photographs for movie production, the 35mm has captured the largest segment of the photographic market and has the widest selection of film types and lenses. For most good 35mm cameras,

you can purchase lenses from panoramic fisheyes that deliver full sky coverage to 2000mm ultra-telephotos for long distance photography. Today you can choose between a completely manual 35mm or fully automated models that determine the proper exposure themselves and allow you to concentrate on the subject.

For astrophotographic purposes, the manual is best — otherwise the camera's internal exposure meter will confound your own attempts at determining an accurate exposure. Sometimes an automatic shutter will lock open for days if its light meter measures too little light for the exposure. This is frustrating, so if you use an automatic 35mm, set it on manual before attempting astrophotography.

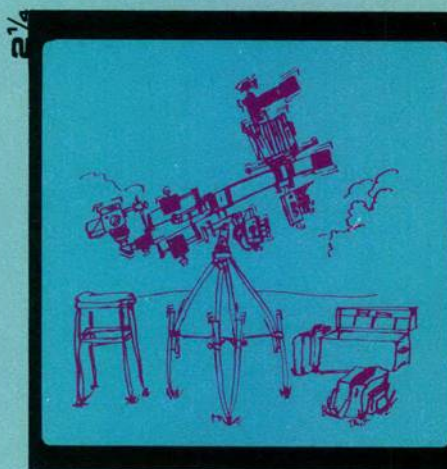
The real beauty of 35mm cameras comes from its vast array of available lenses. You can take either wide angle, or telephoto piggyback views simply by changing the lens. With the lens removed and the proper adaptor inserted, you can use it coupled to the drawtube of your telescope. You can then take pictures at the prime focus of your telescope and obtain crisp shots of the Moon and the planets. If you have a wide range of adaptors, you can take eyepiece projection photographs for detailed views of the planets — or even negative projection photos using a Barlow lens, to achieve an even larger image on the film.

Then you can put the normal lens back on, attach the camera to a tripod, and take stunning, unguided photos of constellations, meteor and star trails, and other wide field areas. You can also take the family portrait and vacation travel shots with the same camera. The 35mm's versatility is unmatched.

The only cameras that come close to giving the 35mm a run for its money are the 2 1/4" medium-format types and the 6x7 and 6x9 centimeter models. Probably the most famous camera in this size is the Hasselblad — among photographic purists, it is the *only* camera. The Hasselblad and other 2 1/4 cameras have one big advantage over the 35mm — the film they use is almost three times as big. They also have as wide a range of lenses as the 35mm. The drawback is their price. Medium-format cameras like the Hasselblad or the Mamiya cost thousands of dollars — more money than most astrophotographers want to put into a camera system. But, as with most things, you get what you pay for. NASA has always used a Hasselblad — but they also use a Nikon 35mm. Both cameras perform flawlessly in zero gravity and any NASA photos you see from the Moon or from space were made with one of these two cameras.

For astrophotographers who want to

use a medium-format camera, the rewards offered by a 2 1/4 outweigh the drawbacks. Since a wide variety of lenses and films are available, these cameras do everything a 35mm does and the images they produce will be superior because of the larger film. A 10-minute guided exposure of Orion on a 2 1/4-inch slide is breathtaking. You



will see much more detail than on a 35mm, and you can enlarge the original to 16"x20" without the slightest loss of resolution.

If you want ultimate image quality in your astrophotos, but don't want to sacrifice versatility and ease of operation, consider one of these medium format cameras. The initial cost will be high, and additional lenses are expensive, but you will produce better quality pictures than you could with a standard 35mm. As a medium-format camera is a little larger than 35mm, you will have to custom engineer all your own telescope adaptors. But it's worth the trouble if you want the best images money can buy.

Full Size Models

The next step up in size is the 4x5 camera. These take 4x5-inch sheet film and include many old “press cameras.” With them you'll have to remove and insert a new piece of film for each exposure, because the film is not sold in rolls — only in single sheets. Try this outside in the dark sometime and you'll see that it takes practice. Of course, like the 2 1/4, the 4x5 delivers an even larger image — but you are getting to the point where the physical dimensions of the camera begin to outweigh the advantages of a bigger picture. World War II surplus lenses like the Metrogon or Aero-Ektar that were used for surveillance operations produce very good images for a 4x5 format. But they are pretty big and heavy, and coupling them to your telescope becomes a problem. It is all but impossible to take prime-focus pictures, or negative or positive projection photos because you can't stick the camera up to the drawtube of

your scope. However, mechanically inclined observers can make custom platforms or mountings for these cameras. Then they become very useful for all-sky surveys and wide-field photography. (See "Astrographic Cameras," *ASTRONOMY*, November 1976.)

The 8x10 camera fits into an even more esoteric class of large format photography. Old Graflex models are the most commonly available. When you get into this neighborhood, you're flirting with some tough mounting and guiding problems. In fact, unless you have a 10-inch scope, or an exceptionally sturdy mounting, it is not a good idea to piggyback with a camera this large. Like the 4x5, these cameras only accept one piece of film at a time. That means you have to take out exposed pieces of film and keep them someplace dark until you can get around to developing them. You should also plan on developing them yourself because it is a slow process and most commercial photofinishing labs don't want anything to do with this kind of film. Your film choices are also limited by the larger format. Some of the favorite emulsions that 35mm photographers use are not available in this size — Ektachrome 400 for example. But you can buy a wide range of black-and-white emulsions, as well

as color negative film. Unfortunately, this last type is not particularly suited to long exposures because of its reciprocity failure.

When you choose a camera, keep in mind that large format 8x10s and 4x5s are more at home in the professional photographer's studio than on the side of a telescope. Their bulk makes them difficult to work outside a very controlled environment — such as a studio. But their large film size and extraordinary detail-producing power are considerable advantages to the astrophotographer. You can make huge enlargements with virtually no loss of detail and still preserve very fine grain.

All these cameras — 110, 126, Polaroid, 35mm SLR, 2¼, 4x5 and 8x10 — are designed for straight photography but can be adapted to astrophotography by various means. But two other camera types have no practical application in conventional photography, and are used solely for astrophotography: the cold camera and the Schmidt camera.

Cold Camera

The cold camera holds a piece of film in a compartment chilled to a temperature well below zero by dry ice. Cooling an emulsion lowers its reciprocity failure and improves normal film characteristics. Color

balance and response to low levels of light — both important variables when photographing astronomical objects — are greatly enhanced by a cold camera. While you can make such a camera at home (see "Cold Cameras," Part I and II, *ASTRONOMY*, February and March 1977), some models are available commercially.

Cold camera photography caught on in popularity during the late sixties and early seventies as backyard astronomers learned they could produce "observatory quality" photos with readily available films and equipment. One of the biggest problems with cold cameras is loading the dry ice or other cooling agent and the small pieces of film — usually single frames of 35mm — into the camera. Because of the very low temperature, dew often forms on the film and ruins the exposure. Unfortunately, you don't know this until you develop your film. Since cold-camera photography uses non-standard lengths of film, you'll also have to develop it yourself. Be prepared to learn how to process either black and white or color film. Cold cameras produce very nice photos, but the hassle sometimes can overshadow the benefits. Loading small pieces of film into the plateholder in total darkness, suffering finger-frostbite from the dry ice, and then developing tiny strips of film — usually color — make the cold camera a tool best used by the very experienced astrophotographer.

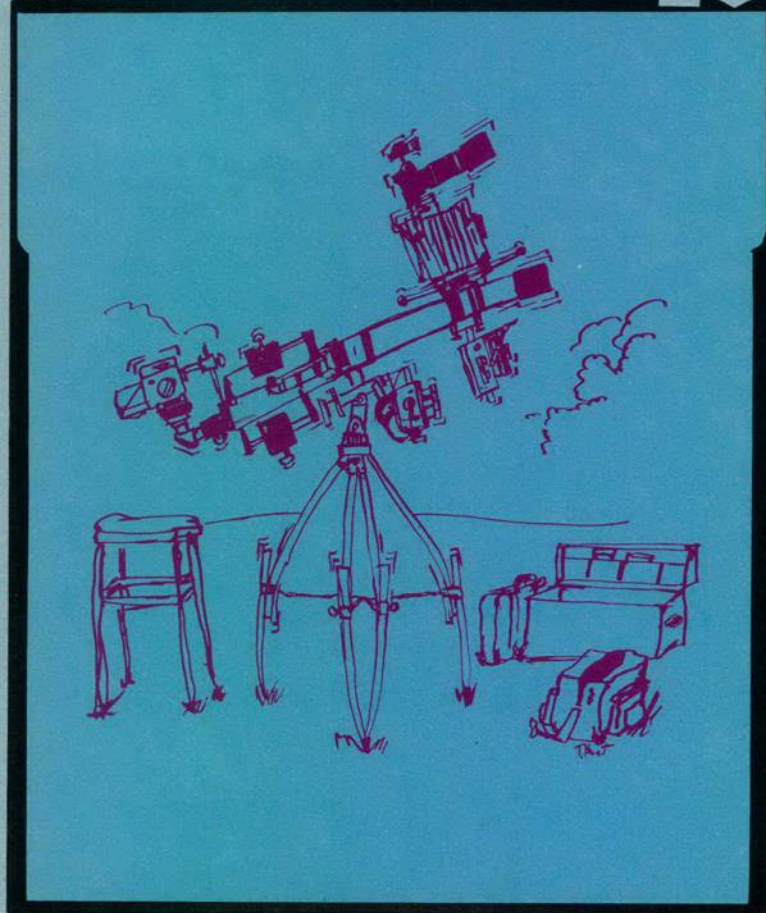
Schmidt Camera

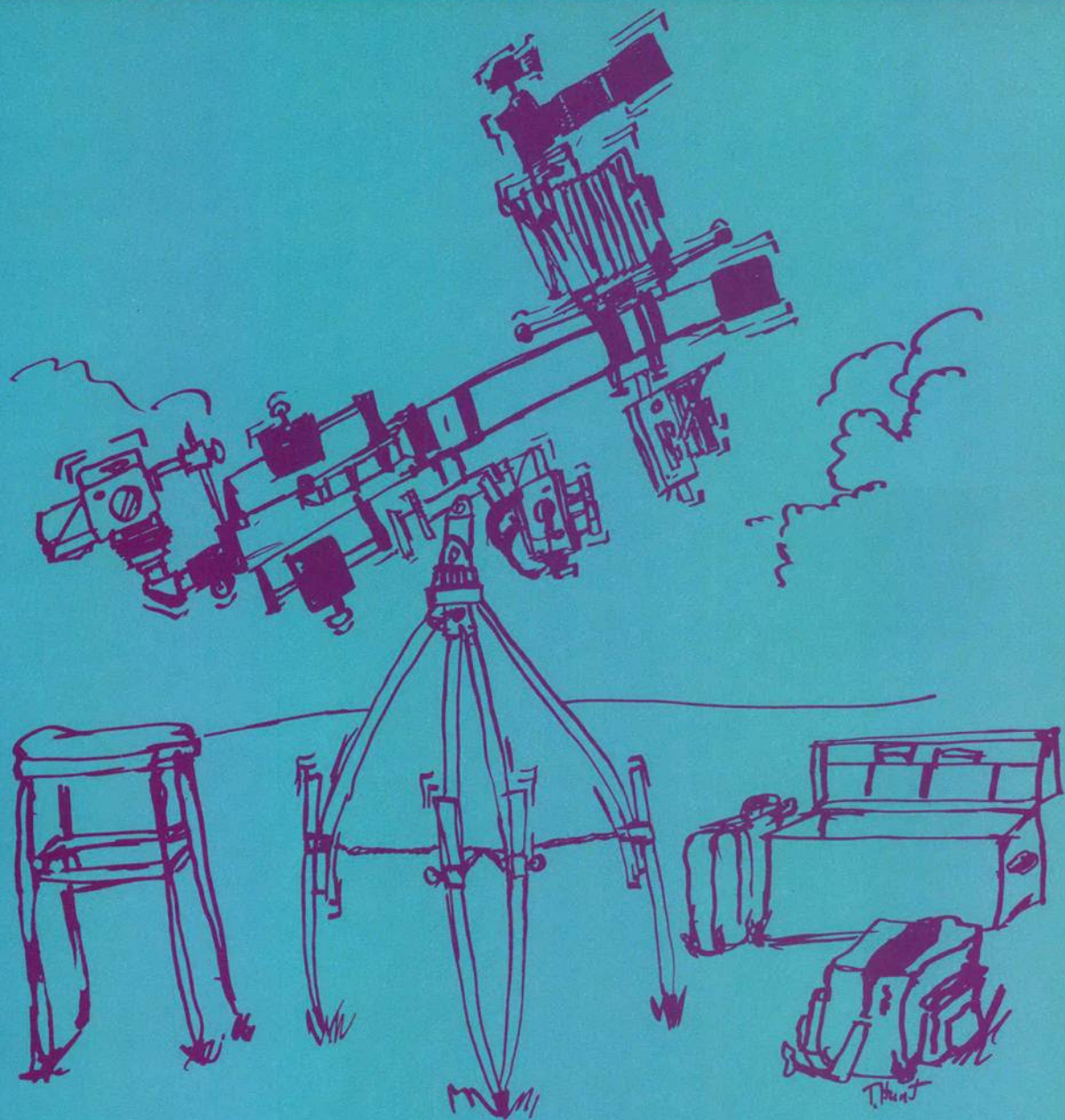
The other camera developed exclusively for astronomical photography is the Schmidt. With a Schmidt's photographic speed and sharp images, you need only use a short exposure because the camera focuses the faint light of the sky into a wide-field photograph that is optically perfect from edge to edge. This speed and sensitivity make the Schmidt ideal for astrophotography. One major problem, however, is that this wonderful image is curved, and to record it, you must bend the film.

During the 1930s, the Schmidt camera's very fast optical system came into wide use throughout the world's observatories. Since then, it has been used to make many of the star atlases we use in the backyard.

Smaller Schmidt cameras are now available to the backyard astrophotographer and offer all the advantages of their observatory counterparts. They seem to be exotic pieces of equipment, but are essentially just a special film holder to bend the film with a very fast lens attached. You can't use a whole roll of film in a Schmidt, and like the 4x5 or 8x10 you'll have to use single pieces again. Although you won't have the problems associated

4x5





with a cold camera, the Schmidt has other drawbacks. First is the price: they are expensive, and since they can only be used for wide field coverage some observers can't justify their high price tag. It's too bad they aren't more versatile, because they produce stunning photographs — if properly guided — and make great patrol cameras. Then there's the curved film problem, which is easily enough solved by the special film holder. Once again, you will have to custom design a coupling device so they can ride piggyback on your telescope. Because their wide views are useless for

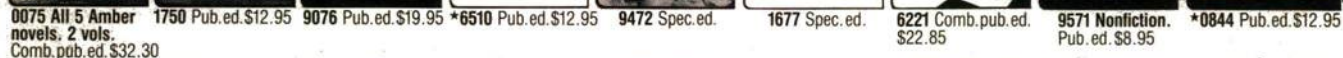
photographing the Moon or the planets, Schmidt cameras are also better suited to the experienced astrophotographer. Until you have mastered the basic skills, stay away from these finicky instruments.

This just about completes the list of choices that face backyard astronomers who want to buy a camera. Your decision should depend on what kind of equipment you already own, and what kind of photography interests you most. Once you answer these questions, you can begin reading product literature and looking through the classified ads in

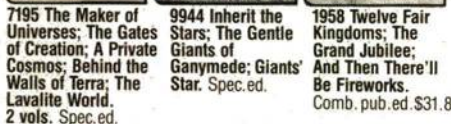
astronomy magazines. Set a budget that you can realistically stay within then go out and buy the best camera for your money and your needs. Always remember that you get what you pay for, and beware of those "good deals" that might backfire when you get the first roll of film back, or strap you with a camera that is so difficult to use it totally destroys your interest in astrophotography. And by the way, after you buy that perfect camera and become really good at using it, how about sending some of those pictures our way?

— Berry Brunk

through other dimensions of
mind and matter...



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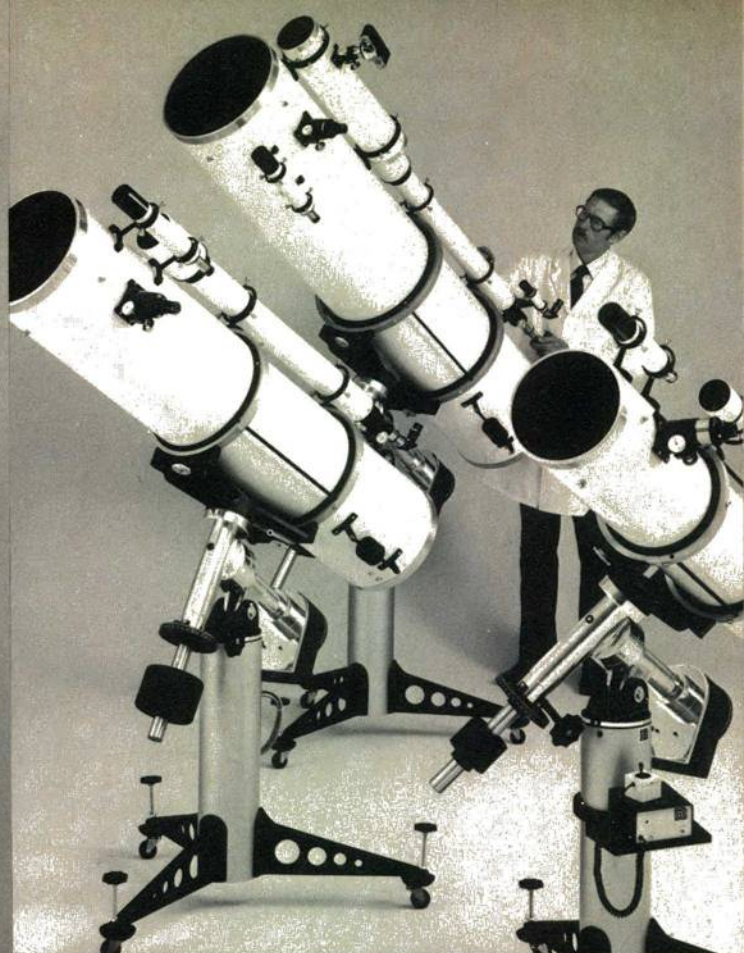
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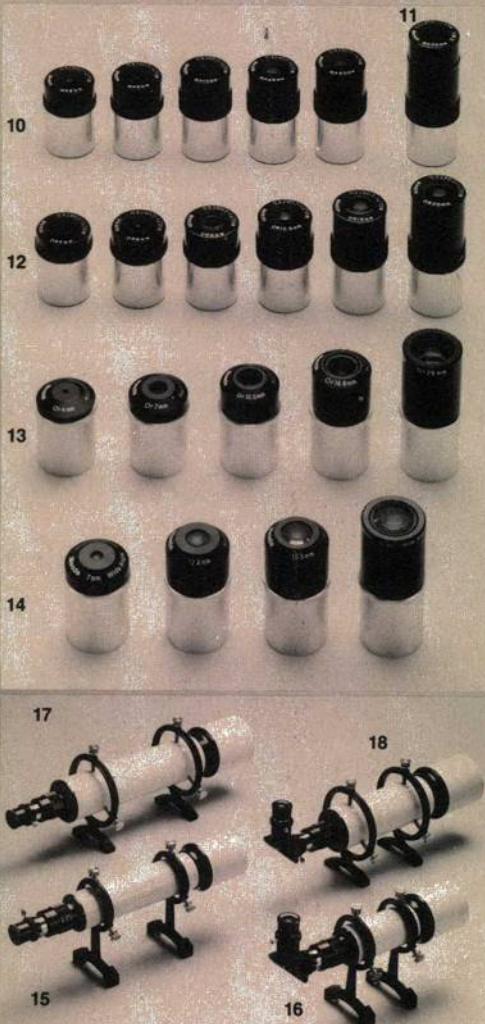
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watch the skies

by
John Mood

Dedicated to R.A.R. Tricker, dean of atmospheric optics physicists.

You say you don't have the time you'd like for stargazing — driving to work at dawn, forty-five minutes at dusk on crowded freeways to get home. Too tired to get your 9-inch Quasetron out of the closet? And weekends are set aside for home repairs, spending hard-earned money on "necessities," or making up some much-needed time with spouse and children. Or you just can't miss the next episode of "Dallas" or "Monday Night Football."

And even if you did have the time, there's always that blasted cloud cover. Three-fourths of the time you can't even see the Sun or Moon, much less the stars or anything else. And when there aren't any clouds, there's that slime-green dirty haze that seems to hang over the city. Or it's that one clear and beautiful night of the month and there's a Full Moon.

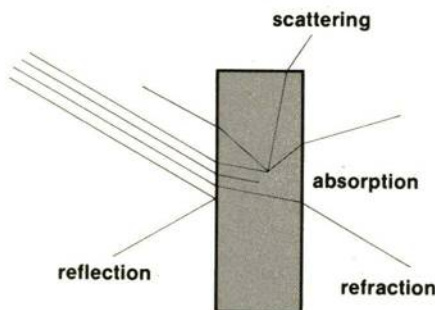
And on that rare day when all these problems magically disappear, you drag out your telescope, set it up in the backyard (overlooking the grass that needs cutting and tripping over the still-broken hibachi), line the finderscope up, then slew it around to get M-42 in your sights only to discover the light pollution is so bad you can barely make out Sirius or Betelgeuse. And it's not just the general city light pollution, either; it's the street light down on the corner and Frightened Fred's newly installed mercury vapor light on top of his barbed-wired, eight-foot high chain-link fence that really makes it all impossible.

It's enough to make you want to take up stamp-collecting or goldfish. But wait! There are other options.

Take, for the moment, an imaginary journey on an unmanned deep-space probe headed for Slaanki 281, a single G2V star a bit more than seven light-years away. After decades of lonely

flight, the probe nears the planetary system of that star. The pre-programmed sensors detect a likely candidate to land on with a thick water-saturated nitrogen-oxygen atmosphere, and the long-silent retrorockets prepare for landing. Once successfully down, the probe waits for daylight so the television camera can scan the sky and horizon, preparatory to beaming pictures on a seven-light-year journey back to the home planet.

What it sees the next morning is this incredible brilliant blue overhead, gradually and subtly changing to a moderate blue as the camera moves slowly away from the zenith, to a light blue, a pale blue, a very pale blue, and



then finally to a very light bluish white at the horizon. The next day the same scan detects more of a greyish blue at the zenith and the progression to the horizon is even subtler, with not as great a change in hue, finally becoming a very light bluish grey at the horizon.

On another day, the properly filtered camera locks in on the star itself and follows its course during the day as it goes from a very vivid light yellow at zenith all the way through a moderate pale yellow to a very strong reddish orange as it nears the horizon. On a succeeding day, the sky is a medium grey with only slight variations — undoubtedly a thick cloud system has moved in. On still

another day's scan, long lenticular vari-colored clouds give the effect of looking at the "underside" of an arm of a galaxy. And of course, there are times when white or even colored clouds drift through the blue background in the camera's field of vision.

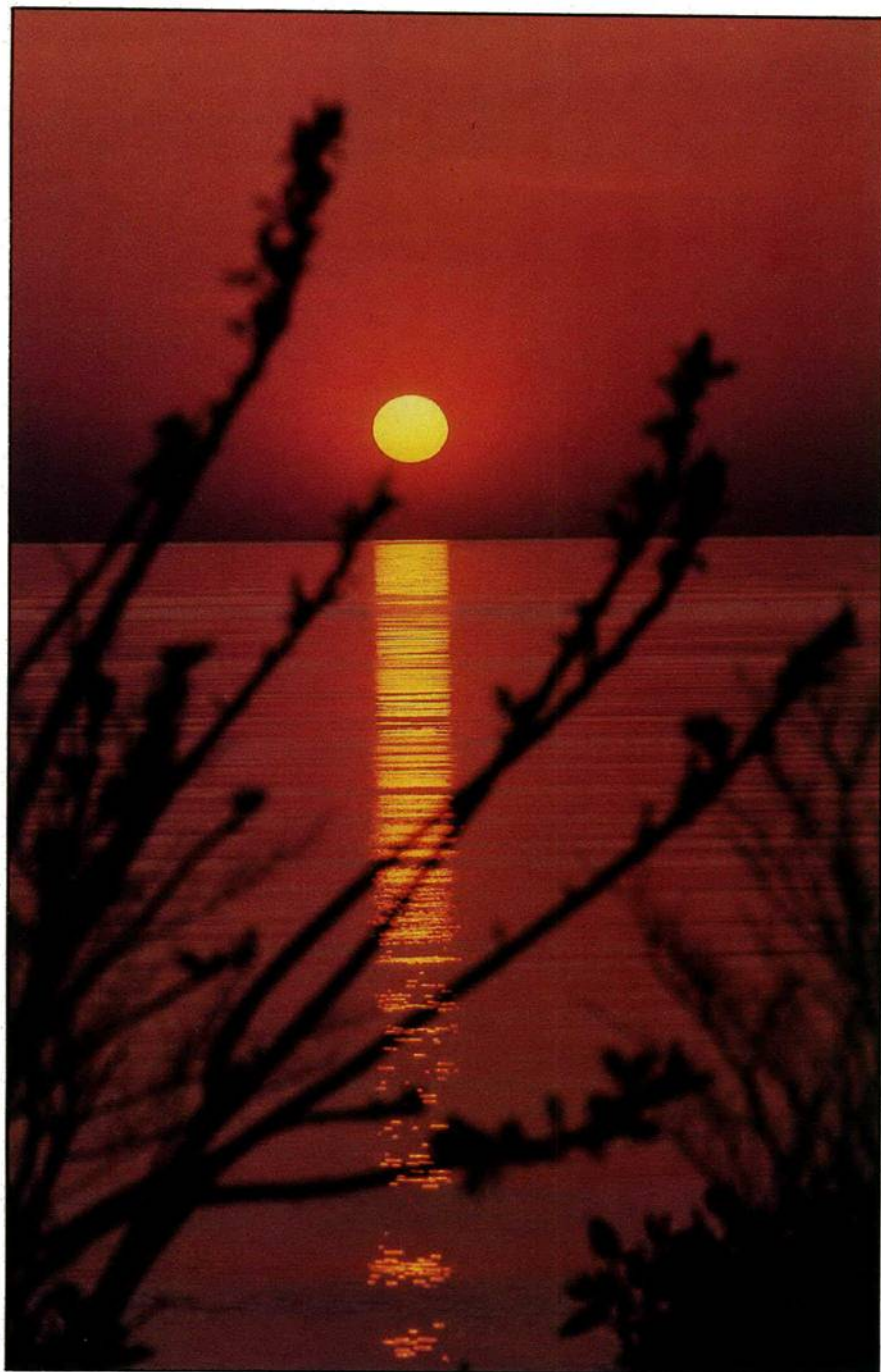
The probe makes even more complex observations in this remarkable atmosphere. Especially intriguing are the unbelievably intricate patterns of hues, colors, shades, lights and darks, and saturations before, during and after sunset, when scattered clouds hover nearby. Puffy pinks like cotton candy, indescribably brilliant patches of iridescent gold dancing on the edges of clouds, reds and oranges and yellows against an almost purple sky — the variations are endless.

Scientists back on the home planet seven years later are enthralled — curiously titillated beyond measure. And millions of viewers of television broadcasts are amazed, clamoring for more and more pictures of these remarkable and breathtaking sights.

Well, of course, we all know these sights. We can see one or another of them every single day of the year. The G2V star "Slaanki 281" of our imaginary flight is actually old Sol, and the unnamed planet is the "third stone from the Sun," our lovely and bounteous home. We have been engaging in just one brief and simple example of a kind of visual astronomical observation available to us all, at any time, anywhere — the enjoyment and recording of what used to be known as meteorological optics

Refraction of sunlight by upper atmospheric ice crystals produced this 22° halo over Torrey Pines Beach, California. Lee Peterson used a Nikon F2 and a 16mm f/3.5 ultra-wide-angle lens to produce this unusual view. The exposure was 1/60-second at f/11 on Kodachrome 25 film.





When the Sun is very low in the sky and setting over water, you can sometimes see a "glitter path" reflected off the tops of waves. On May 20, 1981, this glitter path was photographed in Ontario by A.W. Steinbrecher with a 200mm lens at $f/2.8$ and a 1/125-second exposure on ASA 64 film.

"Nothing there to see," you say. Not quite true. In the first place, the sky is never a completely uniform hue or shade or brightness — it always shows variations. The light at the zenith is different from that at the horizon.

"Watch the skies, please!"

Close Encounters of the Third Kind (1978)

Generally speaking, on an overcast day, the sky is darker toward the horizon, and on a clear day, it is lighter toward the horizon. If the sky appears brighter near the Sun, it is a positive sign of a hazy atmosphere — and more moisture.

Additionally, the very passage of the Sun across the sky produces different effects, culminating in the spectacular vista of sunset — breathtaking even on an absolutely clear day. Naturally, on a solidly overcast day you miss this, but even the slow slide from grey to black has its own charms.

Once any variations appear in the atmosphere such as clouds, invisible layers of heat or cold, moisture or dryness, ice crystals, and even dust or pollutants — once any of these conditions exist, the atmosphere produces more complex light effects, and the vistas become more and more magnificent. We have a vivid contemporary reminder of this in the series of eruptions of Mt. St. Helens. More than a cubic mile of material was ejected into our atmosphere. It whirled around and around in the Earth's constantly changing patterns of winds, and quickly began to affect our sunsets. Even before scientists announced the discovery of layers of volcanic ash at 10 and 13 miles up, sunsets had become visibly redder — the yellows more orangish and the blues more purplish. After the massive Krakatoa explosion in August 1883 — when an entire island vaporized into the atmosphere — sunsets became redder worldwide for three years, and the spectacular Bishop's ring appeared around the Sun. Even urban pollution, as disgusting as it is, changes the light we see in our atmosphere into more vivid hues.

Other conditions of atmosphere and weather create different visual sights. Invisible layers of heat and cold called *inversion* or *discontinuity* layers produce the interesting banding

and is now more frequently called atmospheric optics.

Atmospheric optics is the observation and study of the multitudinous visual effects our particular atmosphere, in all its variations, creates on the particular light received from our particular Sun.

We began to understand the uniqueness of the effects of our Earth's atmosphere on sunlight when we thrilled at the pictures from Viking of a martian sunset. It was the same Sun but a different atmosphere — and therefore, we saw a beautiful reddish sky and surprising bluish sunsets — the exact opposite of ours here. What sights will be ours from under the thick cloud cover of Venus or distant Titan? Or from within the deep gaseous

layers of Jupiter and Saturn? Or, eventually, from space probes to planets orbiting other stars with quite differently composed light?

For now, we have plenty of sights from our own planet. Every day, the changes in our atmosphere reflect, absorb, emit, refract, scatter and diffract the incident sunlight in a virtually infinite variety of combinations, producing the delightful differences in hue, color, shade and brightness of the sky.

In short, on any given day — repeat, on any day, on each and every day of the year — you can observe the varying phenomena of atmospheric optics. And you don't need a telescope or a "clear" sky, either. Suppose it's a completely overcast solid-grey day.

effects we see on the setting Sun. In fact, such a sight is frequently the only way that such atmospheric layers of heat and cold can be detected. Discontinuity layers in the atmosphere can completely bisect the Sun. The effect of these layers as the sinking Sun hits the horizon can produce marvelous visuals — a golden loaf of bread, a hot air balloon, stairsteps, a puffy orange blossom, or a moving stack of pancakes.

Sometimes the Sun will appear as a geometrically exact rectangle, or a precisely carpentered stepladder. Binoculars will assist you in seeing these images, but you must be very careful since blindness can result from misuse. Wait until the Sun is at least halfway set, and even then place the Sun out of your field of view and slowly move the binoculars so that it begins to appear at the edge of the field. If it is the slightest bit too bright, then go no closer!

You can also observe these effects at night with the Moon, planets and stars. With the naked eye or a telescope, you can see some marvelous sights near the horizon, day or night. Particularly striking with a new crescent Moon is the view of multiple attached crescents it occasionally exhibits while setting.

These visual effects of the atmosphere on sunlight are common, though the physicist who studies atmospheric optics is frequently hard-pressed to explain just how they occur. Even the blueness of our sky presented problems before scientists obtained a definitive solution.

But when considering sunsets, we encounter a most unusual phenomenon of atmospheric optics, the near-legendary *green flash*. Actually it is a rather common sight, especially in certain parts of the world. The best place to look for the green flash is over an unobstructed western horizon,

preferably over water — though the central plains of the United States serve almost as well. On a clear day, with no turbulence and no inversion layers, when the setting Sun has very little red in it, you can detect a brilliant emerald green glow just as the very last bit of the Sun disappears. Watch the sky intently because it lasts for only a second, hence the name green flash. It is truly a laser-pure hue. The green flash can be oval-shaped or like a candle flame.

If just a few discontinuity layers exist in the atmosphere, the green flash can appear several times as each segment of the Sun sinks below a layer. There

The "Sun Pillar" is a rare sight caused by sunlight reflecting off of high altitude ice crystals. They usually occur at sunset, but Dan Ostergaard photographed this pillar just before sunrise on March 6, 1981. He used a 50mm f/1.4 lens at f/8 and a 1/125-second exposure on Ektachrome 64.

LIGHT ACTIVITY	CAUSED BY	VISIBLE PHENOMENA
Scattering	Air molecules	Blue sky; White, grey, and colored clouds; Airlight (haze in distance); Twilight; Crepuscular rays; Twilight wedge in east (countertwilight) and Earth shadowline; Anticrepuscular rays (in east); "Ice blink" and "water sky" (cloud maps)
Refraction	Air molecules	Flattened Sun; Irradiation
Refraction	Air molecules plus hotter and cooler layers of air	Banded and segmented Sun; Inferior mirage (the desert effect); Superior mirage (objects appear higher and distorted — "looming," "sinking," "towering" and "stooping"); Lateral mirage; Fata Morgana (castles in the air); Novaya Zemlya phenomenon (Sun appearing before it rises [rare])
Refraction and scattering	Air molecules	Scintillation (twinkling); Green flash (green ray, green rim, green segment); Blue flash [rare]; Red flash
Refraction	Ice crystals	22° halo; 22° parheliion (sun or moon dog); Upper and lower tangent arcs to 22° halo; Circumscribed halo; Parry arcs; Arcs of Lowitz; 46° halo; Circumzenithal arc to 46° halo; Circumhorizontal arc to 46° halo; Supralateral and infralateral arcs to 46° halo; Other contact arcs to 46° halo [rare]; Halo of 8°, 18°, 23°, 33° [rare]
Reflection	Ice crystals	Sun or Moon pillar; Subsun (from mountain or airplane); Parhelic circle (from mountain or airplane)
Reflection and refraction	Ice crystals	22° subparheliion — sun dog — (from mountain or airplane); Subparhelic circle (from mountain or airplane)
Multiple reflections	Ice crystals	120° parheliion (sun dog); Anthelic arc; Anthelic pillar; Anthelion (sun dog); Subhelic arc [rare]; Helic arc [rare]; Subanthelic arc (antisolar arc) (from mountain or airplane) [rare]; Kern's arc [rare]; Hevel's 90° halo and the 90° halo parheliion (sun dog) [rare]
Reflection and refraction	Water drops	Rainbow (and supernumerary, secondary and reflected rainbows)
Reflection, refraction and diffraction	Water drops	Red rainbow
Diffraction	Water drops	Aureole; Corona (colored rings around Sun or Moon); Iridescence in clouds; White rainbow (cloud bow, fog bow, dew bow)
Diffraction	Atmospheric pollutants	Glory; Heiligenschein (dew and dry); Heiligenschein streak; Specter of the Brocken; Green Sun [rare]; Blue Moon [rare]; Bishop's ring [rare]



The skies over Medford, Oregon, produced these multiple phenomena. The Sun's light is refracted, and forms a 22° halo with 22° parhelia or "Sun dogs." At the same time, an upper tangent arc showed faintly at the top of the halo. Lee Peterson photographed this rare display on August 10, 1978 with a 16mm f/3.5 lens and a 1/60-second exposure at f/16 on Kodachrome 25.

are reliable accounts of the phenomenon lasting longer, so be alert! Marcel Minnaert, the Dutch observer and student of atmospheric optical sights, once saw the green flash for twenty seconds by running up the slope of a dyke during sunset, and Admiral Byrd saw it for thirty-five minutes on his South Pole expedition as the long polar night ended with the Sun sliding along the horizon. Occasionally you can see this same effect with the setting Moon, Venus and even Jupiter. Telescopic aid helps with these, however. Sometimes you can see extremely rare blue, violet, and red rays.

A combination of three interactions between sunlight and the atmosphere creates the green flash phenomenon. The Sun is low on the horizon so the yellow and orange light is absorbed by water vapor present in the thick atmosphere. The violet is weakened by molecules of air scattering the light. This leaves red and blue-green. The third interaction, refraction, is less for red, stronger for blue-green. Hence the remaining predominately green hue.

Despite its reputation of rarity, you can see the green flash quite often during sunset over the Pacific Ocean. Green segments show at the tips of the arc of the almost set Sun, and the green ray itself is visible immediately after sunset. Use binoculars — but again take great care not to use them until the Sun is practically set. You can also observe the phenomenon in the midwest — it's certainly flat enough. Sunset is the best time for viewing the green flash, because you'll know exactly where to look.

However, if you can mark precisely where the Sun will rise, especially over water, and know exactly what time sunrise will occur, you can observe the same effect then. This is not true, however, of the layering and banding phenomena and the resulting green segments because the atmosphere is usually quieter in the morning after a night's rest than in the more turbulent evening after a day's work.

Another sunrise or sunset vista visible over water is the *glitter path*, the ladder-like patches of sunlight reflected over the waves. It is a gorgeous sight, brighter at the horizon as it skips over the patterns of waves. Omar Khayyam mentioned the glitter path in his study of the physics of wave phenomena.

A basic principle of the observation of atmospheric optical phenomena is that you should watch all of the sky, all the time — frequently scanning the entire orb. You will be surprised how much you can see at sunset, and how rapid the changes can be. Keep your eye on the east and overhead as well. If you do, then you can sometimes see the phenomenon known as *counter-twilight* or the *twilight wedge* — a subtle mirroring in the east of the colors in the west.

More often, the atmosphere as a whole acts as a giant prism so that during twilight a muted version of the spectrum is visible across the sky — the red-orange-yellow in the west with the blue-indigo-violet mixed down with grey in the east. When the Earth turns, you can see its shadow on the sky in the east, and the spectrum rises overhead, a beautiful greyish prismatic ROY G. BIV — (red, orange, yellow, green, blue, indigo, violet) moving slowly upward in the east until it reaches the zenith, then sliding easily down to the horizon in the west as twilight comes to a leisurely close.

The *crepuscular rays* which frequently appear are even more spectacular. Often these rays will fan out to the south or north of where the Sun set. Sometimes they appear all

across the sky, or in varying lengths or widths, creating wedges of greyish blue and purple between streaks of yellow and orange. Occasionally, rays will appear on the opposite side, creating a gorgeous addition to the counter-twilight. Watch the skies sharply because these rays can appear and disappear in a matter of seconds. I have seen crepuscular rays encircling the entire north half of the sky, streaks of orange climbing all the way from the west up to the greyish-blue zenith and then descending unbroken down to the purplish eastern horizon — a free light show for anyone who looks. Incidentally, though these rays appear to diverge from the Sun, this is only an illusion since light rays are parallel — like the apparent convergence of receding train tracks, it's merely a matter of the viewer's perspective.

"Qu'est que c'est?" asks the cartographer-translator. "Je ne sais pas," replies ufo-seeker Lacombe, "mais c'est beau."

Close Encounters of the Third Kind (1978)

If you live farther north and inland where some of these sights appear less frequently, take heart! You have the compensation of greater opportunities for viewing other equally spectacular atmospheric vistas — halos and arcs around the Sun caused by ice crystals high in the atmosphere.

The most common is a large ring of light around the Sun. Look at it with your hand covering the Sun — you'll see what appears to be a giant halo. In reality, its radius is slightly more than your spread-out fingers held at arm's length. This is the small 22° halo, and it frequently has color — redder nearer the Sun, bluer near the halo, another muted spectrum. More often than not, the sky is darker inside the halo than outside.

But this is only the simplest of ice crystal sights. You can also view mock suns, or sun dogs — technically called parhelia, from the Greek, *par* and *helios*, by the Sun. They are bright spots just outside the 22° halo on the same plane as a horizontal line drawn through the Sun. These can have even brighter spectrum colors than the halo itself. In addition, the parhelic or horizontal circle runs through the sun dogs, the Sun itself and the halo. Additional arcs, tangents and circles can appear, as well as the circumscribed halo, multiple mock suns, the great 46° halo, and a host of other remarkable effects.

What you see will depend not only on the ice crystals present in the sky, but also the elevation of the Sun above

the horizon. Also, the shape and position of these arcs and circles will vary as the Sun changes elevation. The anthelion and anthelic arcs are those on the opposite side of the sky from the Sun. You can also occasionally see a sun pillar, a column of light either above or, more rarely, below the Sun, sometimes even when the Sun has already set. Light pillars can also appear over mock suns. Other rarer displays are double suns and sub-suns (below the Sun — seen from mountains or airplanes, and light crosses — combinations of pillars and arcs, halos of 8°, 23°, 32°, etc.). For the dimmer phenomena farther from the Sun, averted vision will assist viewing.

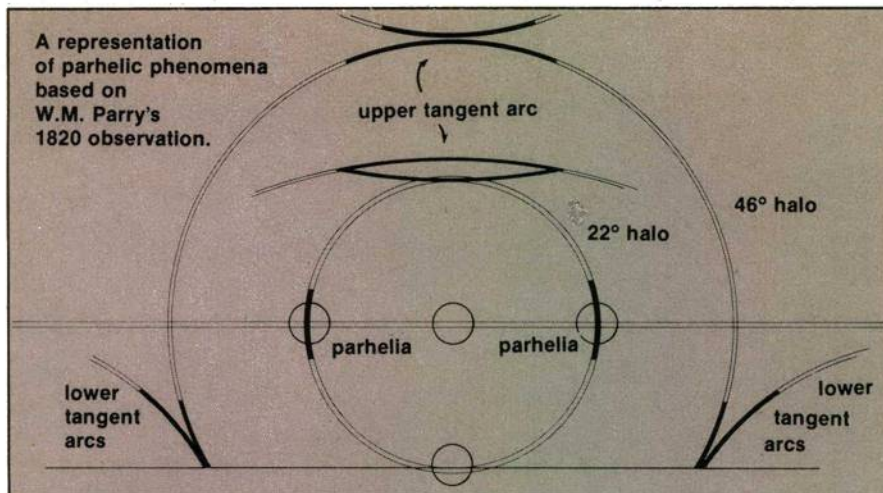
Of course, the brighter of these phenomena can also occur in muted form at night in conjunction with the Moon. And again, you should always look all around the sky, so you won't miss any of them.

A number of complex displays of multiple ice crystal phenomena have been recorded. The most famous is no doubt that of Tobias Lowitz in St. Petersburg, Russia, on June 18, 1790. It lasted for hours and his drawing includes arcs that did not appear all at once. Besides a 22° halo, the display included a 46° halo, numerous mock suns, and mock-suns of mock suns, arcs, circles, and tangents. Other well-known reports of rare displays are by Scheiner in Rome in 1620 (six mock suns and a complete parhelic circle), by Hevel in Danzig in 1661 (four mock suns, a complete parhelic circle and a 90° halo named for him), by Parry in the Arctic in 1820, by Harris in Provo in 1935 (with twenty mock suns!), as well as the famous Easter 1974 display of six different halos observed in southern England and Holland.

Reflection and refraction of sunlight by ice crystals cause these phenomena. The colors result from *refracted* or *diffracted* light. Scientists have determined the precise shape, size, and alignment of these ice crystals, and the angle of reflected sunlight that causes these various phenomena.

You might think that these are rare sights. It is amazing how few people have seen even the most common of these remarkable sky shows. Even "rarer" phenomena are only considered such because so few people look at the sky. These displays probably occur more than half the time at 40° latitude north. On any day with high, thin cirro-stratus clouds, you can see some ice crystal sight. Because these clouds often precede an approaching low weather system, ice crystal halos are traditionally considered the harbinger of bad weather.

You need no preparation or equipment. All you have to do is walk



outside and look up many times each day. Notice the colors of the sky and the position of clouds — especially the higher clouds the Sun might pass through, producing a halo or other display. Above all, keep an eye on the Sun. If a display is present, put on your coat, take a lawn chair out and enjoy the show. Dark glasses might help cut down the glare. The only real requirement is leisure time. Money can't purchase this light show. If you make a thousand bucks at your job this week, you can buy a lot — but you can't buy back the solar display that happened while you were indoors at work. In fact, R.A.R. Tricker, the most famous student of ice crystal phenomena, confesses in *Ice Crystal Haloes* that "for the elderly who have retired, this study is ideal, as the author can confirm from his own experience."

Again, these sights are not all that rare. Even in southern California, where sometimes no moisture will fall for six months, ice crystal halos are visible an estimated fifth of the time. That's seventy-five days a year. In more northerly latitudes, they appear much more frequently. Marcel Minnaert claims he's seen two hundred a year from Holland! — but then he notices everything, as reported in his charming classic, *The Nature of Light and Color in the Open Air*.

You must watch the sky with dedication, glancing frequently around, day or night, every time you go outside. These phenomena appear and disappear with surprising celerity. Other times, they can last virtually all day or night.

Scientists are constantly asking for detailed reports and, most importantly, photographs of ice crystal displays — especially those with unusual arcs. Tricker emphasizes the fact that "the study of ice crystal haloes is a field to which the amateur can make important contributions; there are still theories requiring accurate verification which a photograph can

provide, and unsolved problems — which are likely to have simple solutions if only they can be thought of." Notice his reference to both observation and explanation. In what other area of science can the amateur be encouraged to participate so intimately in the process of making new discoveries and developing new theories?

When you see an ice crystal display, note carefully the elevation of the Sun, which dramatically determines which arcs, tangents and halos will appear.

An alternate method is to note the exact time and place of the display, from which you can then determine the elevation of the Sun. Photographs, either black-and-white or color, are extremely useful to the scientist. A simple camera is fine; a wide angle lens is helpful, but two or more photos with a regular lens are just as useful to the physicist. Robert Greenler has another ingenious approach — photographing the sky as reflected in a shiny sphere — he uses a Christmas tree ornament. Photographs are better than sketches because the appearances and positioning of tiny arcs and tangents can be quite deceptive and fleeting, due to the elevation of the Sun as well as the drift and angle of alignment of the clouds of ice crystals causing the display.

So be alert; who knows, perhaps you'll be one of the first to discover a new phenomenon. Report any unusual displays you see (with accompanying photographs and information on time and place) to the Optical Society of America in Washington, D.C.

The conclusion of "Watch the Skies" will appear in the March Gazer's Gazette and discuss other atmospheric optics including aureoles, coronae, the rainbow and other bows, and diffraction effects.

John Mood has a Ph.D. in literature and philosophy, lives in San Diego, and watches the skies.

how to reduce tracking error

by
Art Huffman

Have you ever picked up your negatives from the lab only to cringe in dismay at the elongated, fuzzy star images you recorded? What went wrong? You surely spent enough time aligning on Polaris — and you know you plugged in the telescope's drive. Is your scope's mounting out-of-whack?

Probably not. Even though an accurate polar alignment is important in producing good long-exposure astrophotographs, it's only half the battle. You'll also need to reduce the *tracking error* in your image — the gremlin that made those long, fuzzy stars.

Careful guiding is the key to reducing this error. Any lapse in your technique will keep you from achieving those crisp, round untraced images you want. You just can't sit back and let the telescope go on its own; you have to monitor the target constantly until the exposure is over. If you don't do this, tracking error will ruin your images and all your other

precautions will be wasted.

During astrophotography sessions you can easily notice the movements that shake the guide star around in your eyepiece. Even a slight breeze can throw off a well-aligned telescope, and all those little shakes and shivers bounce the image around and increase your chances of tracking error. But how much of this variation can you allow before the guide star strays too far, and you ruin your exposure?

One thing is in your favor: You need only be accurate enough to keep errors from showing up in your final prints. Of course, the magnification of your system — the image size it produces — is an important variable in this test. Each variation will set different limits for allowable error.

Let's start with the standard 50mm lens used in piggyback photography and then generalize for additional focal lengths. We will deal with both angular measurement and time, so to

avoid confusion we'll use the notation (') and (") for the angular measure of minutes and seconds of arc. Minutes and seconds of time, when abbreviated, will be written "min." and "sec."

A normal 50mm camera lens for a 35mm camera is rated excellent if it resolves 80 lines/mm. This amounts to an angular resolution of about 1'. A typical zoom lens is rated excellent if it produces half this resolution. This is also the limiting resolution for the human eye, since persons with good eyesight can resolve the double of Epsilon Lyrae — 3' in separation.

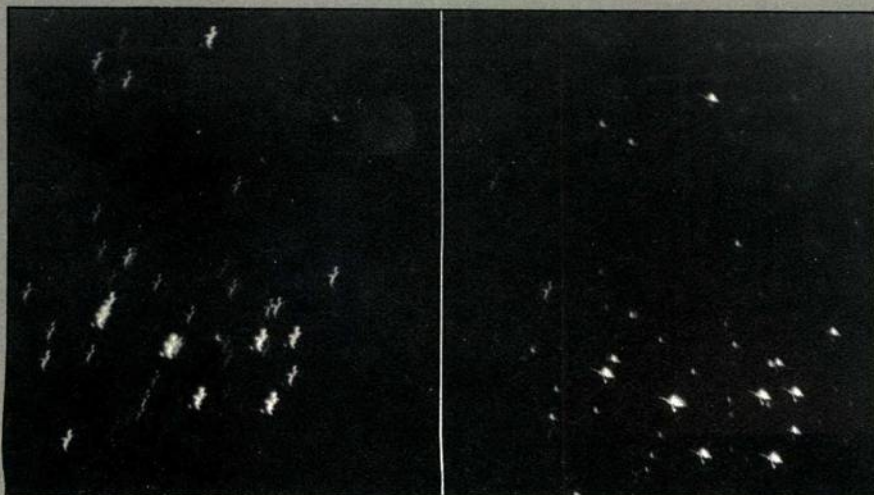
You can check this by calculating the error in fixed camera constellation photography for a 20-second exposure. An unguided exposure of this length produces a barely detectable streak in the enlarged picture. The Earth rotates 360° in 24 hours or 15"/min. Thus, in 20 seconds or a third of a minute, the Earth rotates 5". This is the error that shows up in the fixed-camera picture.

The above calculation suggests that you must track a 50mm lens to an accuracy of 2' to 3' for undetectable errors. This is a good criterion for a reasonable amateur photograph, though an expert astrophotographer might want to try for 1' accuracy. Of course, longer focal length lenses dictate more careful guiding, since their increased magnification makes even this small error too noticeable.

Now let's look in your eyepiece at the guiding cross hairs. Most observers prefer double cross hairs so they can "box in" a guide star. It is much harder to keep a guide star from deviating with single cross hairs, so let's take the easy way out and use the double. What angular size does the inner "box" translate to in the actual piece of sky it encompasses?

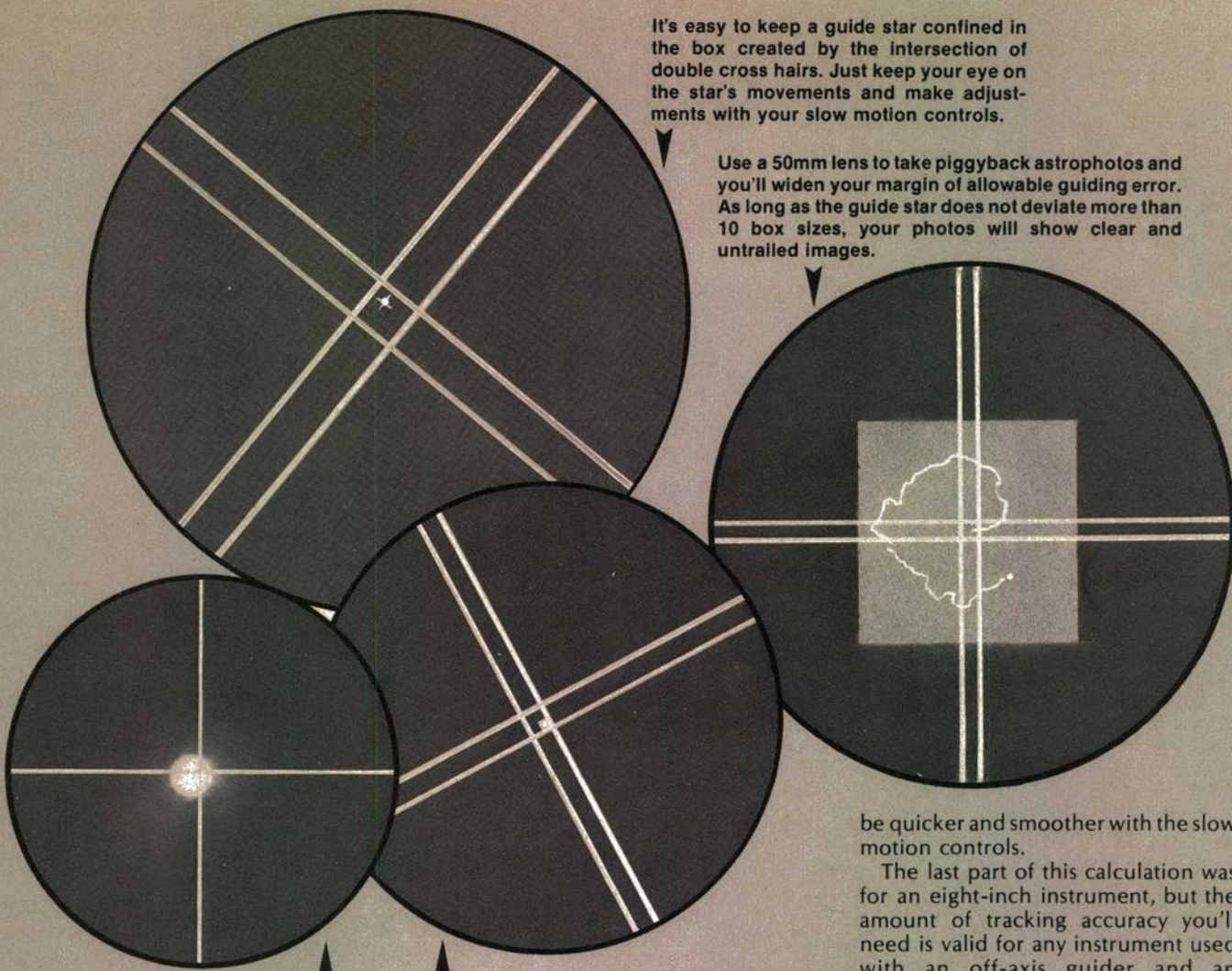
You can determine the size of the box by looking at Jupiter and Saturn and using their known angular sizes.

Talk about guiding errors! These two shots of the Pleiades show what happens if you allow the guide star to drift too far. Both photos are 7-minute exposures on Tri-X, taken through a 400mm lens piggyback on a 6-inch scope. A perfectly guided shot would contain dozens of faint pinpoints that are washed out of this photo. Photo by B. Brunk.



It's easy to keep a guide star confined in the box created by the intersection of double cross hairs. Just keep your eye on the star's movements and make adjustments with your slow motion controls.

Use a 50mm lens to take piggyback astrophotos and you'll widen your margin of allowable guiding error. As long as the guide star does not deviate more than 10 box sizes, your photos will show clear and untrailed images.



You can't "box in" a star with a single cross hair eyepiece, so you'll have to use a different method than you would with double cross hairs. Just defocus a star so it becomes as large as the allowable error and keep the enlarged blob centered on the single cross hairs. Make sure you pick a star that is bright enough to show up even when it's defocused.

Suppose that with an 8-inch $f/10$ instrument the box size is about 60% the diameter of Jupiter and just larger than Saturn when these planets' angular sizes are 37" and 17" respectively. You can conclude, then, that the box size is about $1/3'$ or 20".

So for piggyback photography with a 50mm lens, the guide star must not deviate more than 10 "box sizes" — otherwise you will produce a detectable error of 3'. Of course, proper tracking becomes proportionally harder with higher powered lenses.

With a 135mm telephoto, which is about three power, you must limit the error to about three box sizes. If you use a 400mm telephoto, which is eight power, you'll have to keep the star in the box for the entire exposure in order to produce an unaffected final picture.

If you take photos through a telephoto lens or the telescope itself, you'll have to keep your guide star within a very small area. For a prime focus shot with an 8-inch $f/10$, you must confine the guide star within 9" or $1/4$ of the box shown — or your stars will trail.

With a through-the-telescope photo at prime focus, you'll find it difficult to keep below the minimum allowable error. For example, an 8-inch Schmidt-Cassegrain and a telecompressor lens in the off-axis guider assembly combine to make a system with a 1000mm focal length — or 20 times greater than a 50mm lens. Because of this, you'll have to maintain $1/20$ of 3', or 9" tracking accuracy. In other words you must keep the guide star confined within one-half of the box size! This will be difficult at first, but with experience you'll be able to do it — when the air is very still.

Without the telecompressor, the system has twice the power, and you'll need to track with twice the accuracy — $1/4$ the box size! At this point it makes a lot of sense to use a Barlow lens with the tracking scope to double or triple its power in the eyepiece. You'll have more control with increased magnification, but you'll also have to

be quicker and smoother with the slow motion controls.

The last part of this calculation was for an eight-inch instrument, but the amount of tracking accuracy you'll need is valid for any instrument used with an off-axis guider and an eyepiece since everything scales directly. A longer focal length instrument produces a larger picture scale, but the power the same tracking eyepiece gives is correspondingly larger.

If you don't have a double cross hair eyepiece, use the following procedure to determine scale through the eyepiece. Pick an object of known size, for example Jupiter, or a double like Polaris — separation 18". Then defocus a star (or one of Jupiter's moons) until its disk reaches about 20". Next, find a guide star bright enough that you can see its defocused disk with the same eyepiece focus. If you keep that disk on the cross hairs you can minimize your tracking error.

Keep these simple precautions in mind while you're taking astrophotos and you'll lessen your chances for disappointment when you pick up your next batch of photos from the lab. The blurry, elongated streaks should be gone, and your photos should now match the crisp and beautiful stars and nebulae you saw through the eyepiece. It's just a matter of practice.

Art Huffman teaches astronomy at UCLA. His last article in ASTRONOMY was "Keeping Warm While Stargazing," December 1980.

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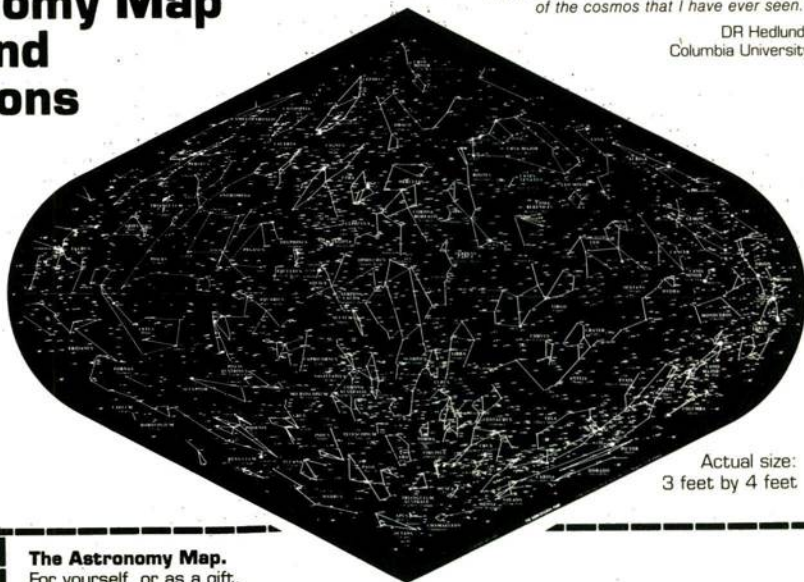
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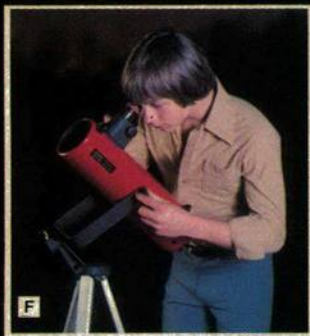
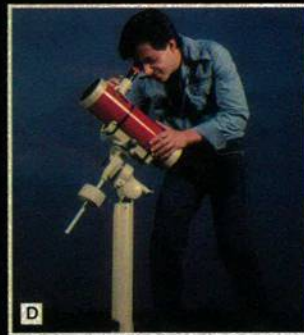
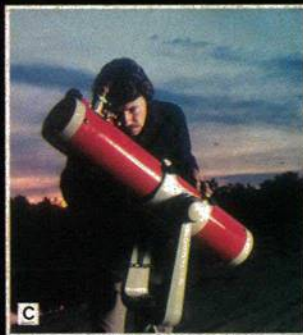
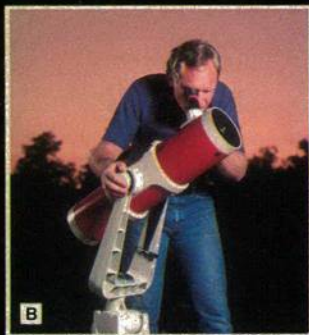
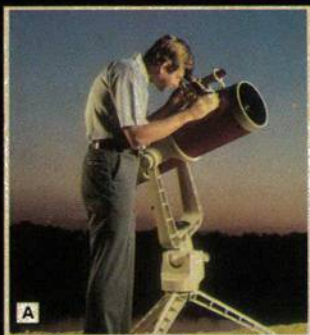
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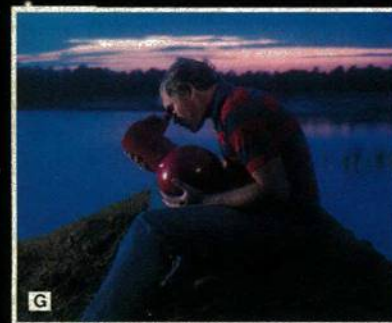
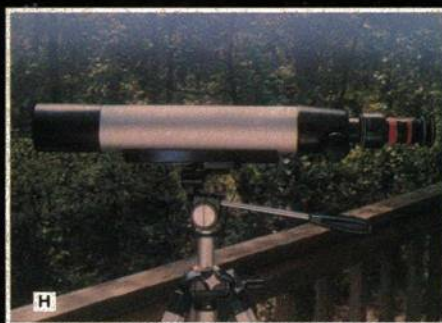
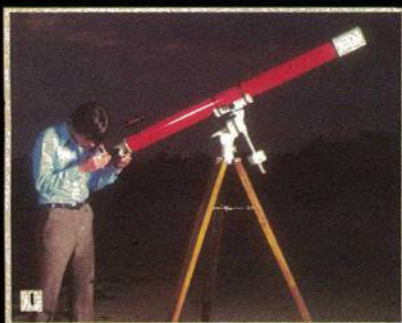
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With the Celestron 11, the solar system becomes a *place* with which you can become familiar, rather than just names in a textbook. With the optional 5-inch off-axis solar filter you may leisurely study the granulation and sunspot structure of the sun's turbulent photosphere (visible surface). The inner planets have easily identifiable phase changes; and under clear, steady skies at high elevations, faint violet markings can be occasionally glimpsed on Venus. Jupiter and Saturn are presented to you with image scale and clarity that easily permit serious study and photography; the details and colors on these gas giant planets are breathtaking. All the other objects from the Moon, Mars and outer planets to the ephemeral comets and faint asteroids are targets for your study and appreciation.



C11 Telescope on optional Wedge and Tripod

LARGE-APERTURE, MULTIPURPOSE TELESCOPE

Deep Sky Observing — viewing the stars, galaxies, clusters and nebulae beyond our solar system — with the Celestron 11 is an exciting pastime. Objects which appear amorphous when viewed through smaller telescopes will, with the C11, appear to have structure and definition. Color is visible in some of the smaller planetary nebulae, and smaller galaxies, such as the companions of M31, M32 and NGC205, now have a definite nucleus and surrounding halo of star-stuff. Globular clusters are better resolved and fainter stars are visible when compared to views through smaller instruments. With an instrument of such capability the 2-inch diameter optional oculars allow spectacular wide-field views of your favorite deep sky objects.

Basic C11 Telescope Specifications

Standard features in the base price:

The base price Celestron 11 is a complete working telescope and includes: Optical Tube Assembly, Visual Back-1 1/4", Star Diagonal-1 1/4", 10 X 40 Finderscope, Fork Mount, Setting Circles, Electric Clock Drive, Clock Drive Cord, Piggyback Mount, Tele-Extender, T-Adapter, Counterweight Bar Assembly, 40mm-1 1/4" Ocular, 25mm-1 1/4" Ocular, 12mm-1 1/4" Ocular, Lens Cap, Carrying Cases, and Instruction Manual.

BASIC C11 SPECIFICATIONS

Optical configuration	 Schmidt-Cassegrain
Clear aperture	 11 in. (280mm)
Effective focal length	 110 in. (2800mm)
Photographic speed (focal ratio)	 f/10
Highest useful visual magnification	 660x
Near focus (approx.)	 70 ft. (21.3m)
Resolution:	
Arc seconds (Dawes' limit)	 0.4
Stellar magnitude limit	 14.5
Image scale — degrees per inch	 0.52
Film coverage (on 35mm format) at:	
100 feet	 1.2 x 7.9 ft. (36 x 24cm)
1000 feet	 12 x 7.9 ft. (3.6 x 2.4m)
Secondary obstruction	 13% (4 in. dia.)
Mounting (equatorial wedge optional)	 fork type
Slow motion controls, both axes	 manual
Electric clock drive — synchronous motor,	
solar rate	 110v, 60Hz, 2 watts
Drive gear diameter	 6 7/8 in. worm
Polar axis diameter	 2 1/4 in.
Setting circles	 Dec. 5 1/8 in., R.A. 8 3/4 in.
Optical tube dimensions	 12.5 in. dia., 23.5 in. long
Optical tube weight	 27.5 lbs. (12.5 Kg.)
Telescope size, swung down	 13 in. (33cm) x 18 in. (46cm) x 30 in. (76cm)
Telescope weight — complete	 57 lbs. (26 Kg.)
Shipping weight — (three cartons)	 115 lbs. (52 Kg.)

SEE OPERATING MANUAL FOR COMPLETE SPECIFICATIONS. AVAILABLE FOR \$1.00

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Celestron® 11 Photographs



Orion Nebula M42

Sombrero Galaxy M104

Galaxy M82



Lunar Disc



Lunar Surface

Globular Cluster M13

Jupiter



AstroNews

Clues on Star Rotation Supplied by Emissions

Is the Sun's magnetic field primordial? Has it been slowly leaking from the solar core since the time of the Sun's formation? Or is our nearest star a great dynamo, with a gentle rotation that constantly generates or renews its magnetic field?

In studying basic questions like these, astronomers are able to gather very detailed data from many points on the solar surface, but with no direct way of knowing what the Sun was like when it was younger, they cannot tell if its rotation and magnetic activity is similar to that of other stars.

The growing ability of

astronomers to detect rotation and magnetic cycles in stars like the Sun is yielding important evidence concerning the basic processes and life-history of the Sun.

Dr. Arthur H. Vaughan and his coworkers at the Mount Wilson and Las Campanas Observatories have developed a new method for measuring how fast stars rotate. Stellar rotation is a fundamental parameter in theories about stellar magnetic fields. Very little is known about rotational rates of stars like the Sun, because the speeds are often too small to

measure spectroscopically.

From the new measurements, Vaughan's group has found fresh evidence of a direct connection between the rate of stellar rotation and the intensity of the magnetic field exhibited by Sun-like stars.

As a star turns on its axis in the course of several days or weeks, it presents to an observer a changing view of successive portions of its surface. The surface features caused by magnetic activity are often irregularly distributed, and, as a star's surface rotates across our field of view, any observable

effects of these magnetic features will vary periodically with the star's rotation. This periodicity can be detected even though stars other than the Sun are too distant to be seen as resolved disks.

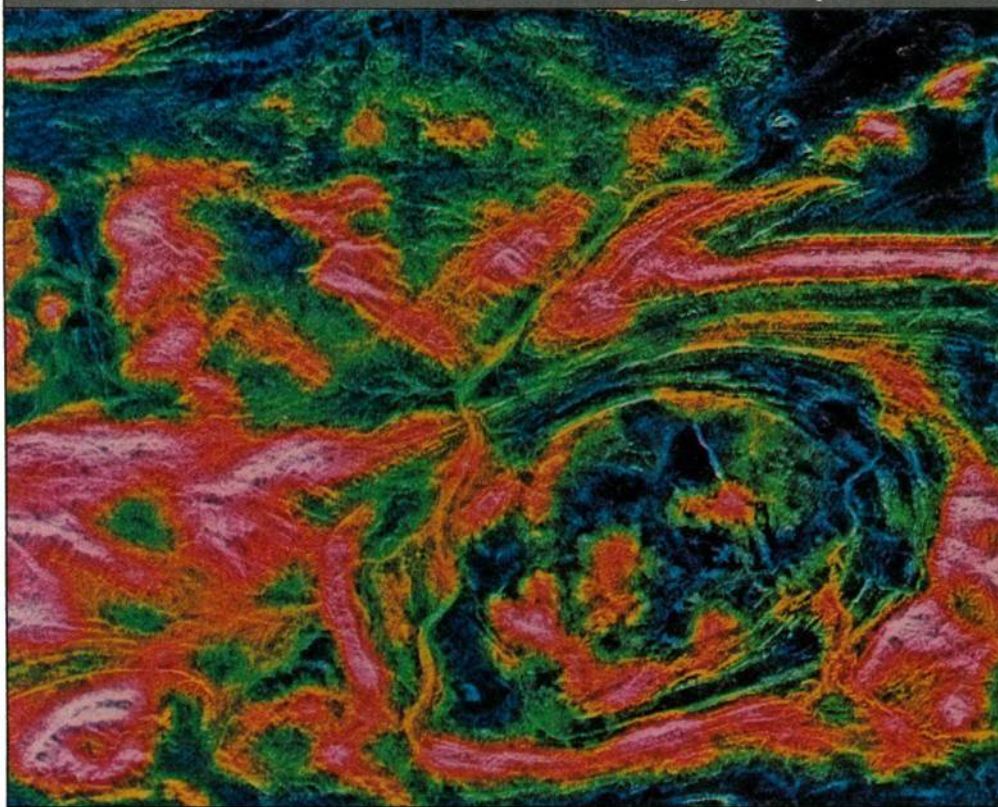
In ordinary stars like the Sun, starspots would be imperceptible. However, we know from studying the Sun that such spots or groups of spots are accompanied by intense emission of light at two particular wavelengths. These are the H and K lines of ionized calcium that are visible through the Earth's atmosphere. By measuring the strength of these emission lines relative to the strength of a star's light at neighboring wavelengths, Vaughan's group was able to study stellar magnetism and to detect effects of rotation.

Vaughan's group tested this method and gathered considerable data during 1980 using the 60-inch telescope at Mount Wilson. Of the 54 stars observed, more than half showed periodic variations in H-K flux sufficient to determine rotation periods that were identified by simple inspection of data or by computer analysis. In those several cases where rotation had been previously determined by the spectroscopic method, agreement was good.

In analyzing their data, the scientists found correlations between the rotation rates of stars and the durations of their magnetic cycles. The results were surprising: rotation periods appeared unrelated to periods of magnetic cycles, except that magnetic activity cycles of 10-12 years were found almost exclusively among stars with rotational periods longer than about 20 days.

They found that, among stars of a given spectral type, the faster the rotation, the greater the average level of a star's magnetic activity (i.e., its observed H-K emission). The Sun itself fits the relation derived from the stellar observations. Similar results have emerged recently from studies of stellar X-ray

Not Rain, or Snow or Dark of Night Stops SIR-A



This false color image of a portion of the Hamersley Mountains in Western Australia was processed from data acquired by JPL's Shuttle Imaging Radar-A (SIR-A) when it flew aboard the Space Shuttle November 12-14. The imaging system was carried on the Columbia as part of the first payload of scientific instruments assembled for use on the Space Shuttle by NASA's Office of Space and Terrestrial Applications. Red areas in the photo represent very rough mountain terrain; pink is less rugged; yellow is textured; green is desert-like territory, and blue represents smooth areas — like a dry lakebed. The photo covers a 50-by-100 kilometer area. SIR-A imaged over 10 million square kilometers — 2% of the Earth's surface. Photo courtesy NASA/JPL.

emission by other astronomers using NASA's orbiting X-ray observatory, *Einstein*. The combination of

ground-based and space observations will be helpful in the search for the true nature of stellar and solar magnetism.

New Measurement Made of Neptune's Rotation

Astronomers at Kitt Peak National Observatory have made the most accurate estimate to date of Neptune's rotation rate — a measurement which will give scientists a clearer understanding of how the solar system formed.

The astronomers concluded that Neptune's rotation period is 18.2 hours, plus or minus 24 minutes. Astronomy textbooks copyrighted 1981 give the rotational period as "15-20 hours."

Michael Belton, Lloyd Wallace, and Sethanne Howard came to their conclusion after making 300 infrared observations during seven weeks in 1980 using the Kitt Peak 1.3-meter telescope.

Neptune, four times larger and 17 times more massive than Earth, is one of the least understood planets. It is 30 times more distant from the Sun than the Earth and is now considered the most distant planet since Pluto's highly eccentric orbit periodically brings it closer to the Sun than Neptune travels in its orbit.

Astronomers must learn Neptune's rotation rate to better understand the forces

that affect its atmosphere. Besides giving them an outside perspective with which they can better understand Earth's atmospheric behavior, knowledge of Neptune's rotation rate will help determine its internal chemical make-up and structure. This kind of information gives astronomers insight into solar system formation.

The Kitt Peak researchers said one difficulty that prevents astronomers from determining exactly the length of a day on Neptune is the fact that they can observe only the cloudtops of that planet. The clouds travel at varying speeds, and astronomers can only infer from observations the rotation rate of the planet.

Neptune has been carefully studied for hints that its orbital behavior might be influenced by an undiscovered tenth planet. Astronomers are also speculating about the possible existence of rings around Neptune. It is now the only one of the four Jupiter-like planets without a known ring system.

Shuttle Docking Experiments Aided by NASA's Toy Train

Harry Erwin, NASA microwave expert, aimed his invisible pin-thin laser beam at the bicycle reflector mounted on the smokestack of the Lionel toy train, energized the computer, and switched the engine to "full speed."

Two hundred fifty feet down the rails, the electric engine and its three-car load rolled forward. The computer display recorded five feet per second, give or take 1/10th of an inch per second; distance: 151 feet; accuracy: within a fraction of an inch.

Erwin, head of Johnson Space Center's Microwave and Laser section, was in the midst of a rendezvous and docking hardware

experiment, analyzing different types of laser-tracking systems.

To carry out the test series, he had requested, much to the bewilderment of NASA Procurement, an electric train set, with a high smokestack to accommodate the bicycle reflector, and 300 feet of railroad track.

The toy train, Erwin explained, was the most effective and inexpensive way to test the laser system's ability to measure speed and distance between two moving targets. So Robert Dupstadt, NASA Buyer, ordered a Lionel train.

Erwin then requested a small, lightweight, low-powered laser and computer

system that could measure speed and distance accurately between two stopped or slowly moving objects.

Because, Erwin explained, the Space Shuttle orbiter or other systems in space such as the Space Operations Center would some day need to dock — gently.

"Two parameters we must measure very accurately are velocity and distance at close range," said Erwin. "That rules out existing rendezvous radars which can track a target accurately at long distances, but lose it close in."

"It's the final closing 300 feet or so that need a precise measuring system, one that accurately measures speed and distance at a crawl," said Erwin. "We think we can do it optically."

The search then narrowed to a newly-marketed, low-power diode laser system that sends light energy modulated with ranging tones. The light energy bounces off the reflector back to the laser's

receiver where the computer processes and calculates the time it takes to make the round trip.

One of the first built and about the size of a grain of salt, the laser diode converts electrons to photons and produces an infrared laser beam. The beam, about a millionth of a watt, is visible only through a special image converter.

The laser experiment is being conducted in a blackened 15-foot-diameter steel tunnel to duplicate the lighting conditions that exist in space docking. Once the diode laser rendezvous and docking technique is perfected, a more powerful carbon dioxide laser beam will be installed to confirm the diode system's accuracy and help set a standard.

If all goes well, says Erwin, the minuscule beam of light may guide hundreds of tons of metal to a powder-puff-soft docking in the blackness of space.

Close Encounter with Star Could Cause Comet Shower

Comets, the solar system's most spectacular members, are also the least understood. They have been invoked as agents of processes as diverse as the delivery of life-giving volatile chemicals to the primitive Earth and the extinction of the dinosaurs. Strangely, some recent work may lend greater credibility to both suggestions.

Dr. J.G. Hills of the Los Alamos National Laboratory Theoretical Astrophysics Group has found that a close encounter between our solar system and another star may result in a cascade of thousands of comets into the inner solar system.

The origin of comets has perplexed astronomers for some time. Since they can be observed only in a small segment of their long journey around the Sun and are visible only when interaction with charged particles activates their nuclei, "backtracking" a comet requires extremely accurate data. The gravitational perturbations introduced by the massive gas giants, Jupiter and Saturn, further complicate the tracking.

In 1950 J.H. Oort examined the nearly parabolic orbits of 19 long-period comets and found that they seemed to

come from a Sun-centered shell whose inner edge was 20,000 times the radius of the Earth's orbit, or 20,000 astronomical units (AU). At such distance the Sun is 250 times fainter than a Full Moon, and comets become the farthest members of the solar system, weakly bound by distant Sol. Oort theorized that the gravitational effects of the stars themselves could adjust the orbits of these loosely bound bodies enough to either pull them from the Sun's grip or send them into the planetary region.

The creation of comets so far from the Sun has been a major problem with the Oort Cloud theory. At 40,000 AU the nebula that formed the Sun and planets is not considered dense enough to have allowed the formation of any solid bodies — even the dirty snowballs we call comets.

But Hills suggests that the inner edge of the Oort Cloud is really the outer edge of a much more massive cloud of comets. Hills used analytical techniques for comets of any arbitrary semimajor axis (roughly half its mean distance from the Sun) and found that while stellar perturbations are strong enough and frequent enough

to knock Oort Cloud comets into the planetary region, only infrequent, close stellar passages would liberate comets much closer to the Sun — around 3000 AU.

A 3000-AU passage of a solar-mass star has occurred about nine times since the birth of the solar system, Hills estimates. The effect of such an encounter is what he describes as a "comet shower."

"The duration of a shower associated with a stellar passage at 3000 AU is about four orbital periods," or about 700,000 years, says Hills. He calculates the "comet flux" over this period to be 10,000 comets per year or one comet per hour entering the realm of the planets. They are quickly flushed out of the solar system, either by adjustment into short-period orbits and destruction by the Sun, or "pumped up" into the Oort Cloud by encounters

with the gas giants.

The formation of comets so near the Sun is far more reasonable than formation in the Oort Cloud region, Hills said, adding that the "observed Oort Cloud is the required final product of any comet cloud with a radius of 10 AU."

Comet collisions with Earth have been considered relatively rare events, occurring between 10^6 to 10^8 years. But during a comet shower, 7000 comets would pass within 2 AU of the Earth every year. Cometary collision could occur between 10 to 200 times during a shower, and Hills suggests that we should begin to look for evidence of entire comets hitting the Earth. "It is tempting to join the 'me too' parade and suggest that this bombardment could have led to the extinction of the dinosaurs," he said.

— Francis Reddy

Astronomers May Have Found Evidence for Water on Ceres

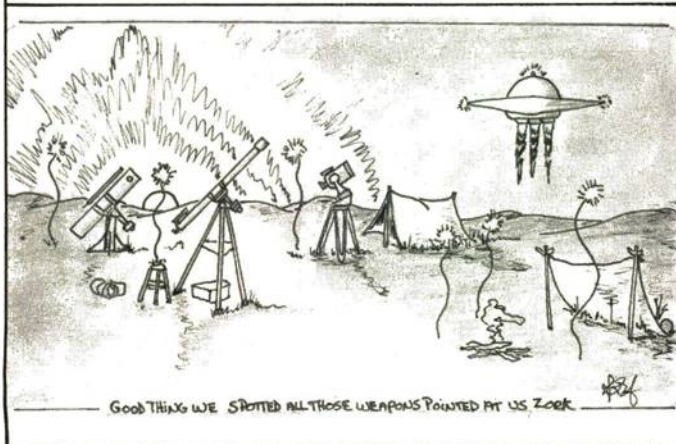
Astronomer Larry Lebofsky and his coworkers at the University of Arizona have recently measured the spectrum of Ceres — the largest known asteroid at 600 miles in diameter — in the infrared, and have found evidence for water molecules in the minerals on its surface. These water-bearing minerals are believed to be similar to the clays which are abundant on the surface of the Earth. Comparison of the Ceres' spectrum with the spectra of terrestrial clay minerals suggests that 10% of the total weight of the asteroid could be water. Most of this water would escape from Ceres'

surface rocks if they were heated to just above the boiling point of water.

Ceres' surface is actually at a temperature well below the freezing point of water, because it orbits far from the Sun between the orbits of Mars and Jupiter.

The astronomers have also found evidence for a small amount of ice on the surface of Ceres. This ice forms when some of the water in the clay minerals is "frozen out" of the rocks because of the low temperature.

The surface of Ceres probably resembles the permanent frost of the polar Earth where water is perpetually frozen.



Cartoon by S. Faworski

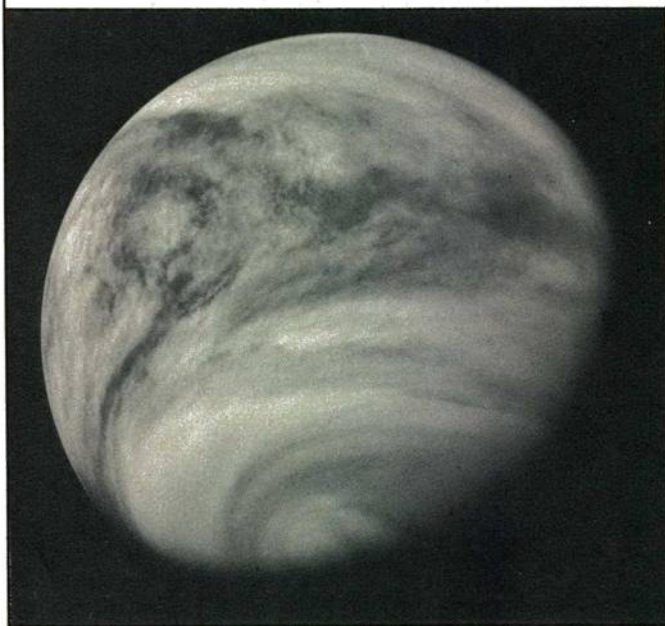
NASA Shuts Down 26-Meter Deep Space Antennas

Three 26-meter tracking antennas operated by the NASA Deep Space Network at Goldstone, California; Madrid Spain; and Canberra, Australia, were shut down on December 1, 1981, because of reductions in NASA's operating budget and the declining workload of the network. The stations will continue to operate 34 and 64-meter deep-space tracking antennas.

The shutdown will reduce

the tracking and data-acquisition capability of the Deep Space Network by 30 percent — providing that much less support for NASA planetary spacecraft. Currently the Deep Space Network is supporting Voyagers 1 and 2, Helios 1, the Mars Viking 1 Lander and Pioneers 6 through 12.

Terminating operation of these three antennas will save \$7.2 million per year beginning in Fiscal Year 1983.



Venus' Clouds May Be a Chemical Lab

NASA Photo

Venusian Atmosphere May Create H₂SO₄

In 1973 astronomers discovered that the upper clouds of Venus contained droplets of sulfuric acid. In 1979 the Pioneer Venus spacecraft sent probes into the venusian atmosphere and detected small round droplets of sulfuric acid as well as crystalline particles. This discovery brought to mind the lead chamber process that chemists used around the turn of the century to manufacture sulfuric acid.

In this process, sulfur dioxide is mixed with oxides of nitrogen and then sprayed onto the sides of a very large lead-lined chamber. Droplets of sulfuric acid form inside the chamber, collect on the bottom, and are then

recovered and sold to industrial chemical works. In the manufacture of sulfuric acid, solid white crystals of nitrosylsulfuric acid would occasionally form in the cooler parts of the chamber.

These crystals were also identified in the venusian atmosphere in 1979 by Pioneer's cloud particle spectrometer. Godfrey T. Sill of the University of Arizona proposes that they are produced through the same functions that operate in the earthly lead chamber process.

In the dense lower clouds of Venus, nitrogen oxides convert water vapor and plentiful sulfur dioxide into sulfuric acid and nitrosylsulfuric acid. Pure

sulfuric acid does not absorb much ultraviolet radiation from the Sun, but when nitrosylsulfuric acid is dissolved in sulfuric acid, the compound readily absorbs ultraviolet light and colors the acid droplets yellow. The clouds of Venus exhibit this property.

Nitrogen oxides have not yet been discovered in Venus' clouds, but only small

amounts are needed for the process to occur, and those oxides could be recycled as if they were catalysts. One intriguing possibility is that nitrogen oxides could be formed, as they are on Earth, in the lightning flashes of storms. Venus may create sulfuric acid in the same way as the old lead chamber, but minus the lead and the chambers.

Regulating lignin production has significant economic value. Although lignin is vital to producing the wood of trees, it is a nuisance in some applications.

For example, it must be removed before conversion of certain wood products into paper and plastics.

This information may be useful to space colonizers who will need to understand plant growth patterns under weightless conditions in order to increase their food production.

The experiment will be carried out in a breadbox-sized plant growth unit containing six 25-centimeter high plant growth chambers which resemble thin, rectangular terrariums. These six receptacles, built from aluminum and a special heat-resistant polycarbonate material, will house two rows of eight seeds each in sandwiches of moist sponge and filter paper. Oat and bean seeds and pine seedlings which have already been germinated will be used in the experiment. Pine sprouts take more time to germinate than the Shuttle mission will provide, so they have been chosen instead of seeds.

The six plants in the six chambers will receive 14 hours of artificial sunlight from sunlamps each day.

"When the Shuttle lands," says Tremor, "the sprouts will be taken out for examination immediately — possibly even before the astronauts are out."

CALENDAR

March 15-19. Thirteenth Lunar and Planetary Science Conference. NASA's Johnson Space Center, Houston, Texas. Contact: 13th LPSC, Lunar and Planetary Institute, 3303 NASA Road 1, Houston, TX 77058.

May 18-22. Saturn Conference, Tucson, Arizona. Contact: M.S. Shapley, University of Arizona, Lunar and Planetary Laboratory, Tucson, AZ 85721.

May 26-30. Amateur astronomy and telescope making conference sponsored by the Astronomical League's S.W. Region. Fort Davis, Texas. Contact: George D. Ellis, 7117 Misty Meadows Dr. S., Fort Worth, TX 76133.

July 18-August 8. International Workshop for Amateur Astronomers (I.W.A.A.). Havelte, The Netherlands. Contact: Niels van Weersen, Sand-Ambachstraat 17, 2691 BL 's Gravenzande, The Netherlands.

July 21-24. ALCON '82 — national convention of the Astronomical League including ALPO, IAPPP, IOTA and National Deep Sky Observers annual meetings. Peoria, Illinois. Contact: ALCON '82, P.O. Box 5203, Peoria, IL 61601

Shuttle Experiment Will Study Seed Growth in Zero Gravity

The third flight of the Space Shuttle, scheduled for March 1982, will carry the first biology experiment designed for an STS flight.

The experiment will study the effect of gravity on the formation of lignin — the woody substance that gives plants their structural stability. John Tremor of NASA's Ames Research Center, Mountain View, California, and Ronald Mancini will manage the project in conjunction with principal investigator Joseph Cowles of the University of Houston.

By watching seedlings grow in the microgravity environment of space, scientists expect to learn more about lignin synthesis and how wood is formed.

Tremor and other scientists believe that plants will grow upward in response to the

attraction of artificial sunlight, despite a lack of gravity. Since roots are less responsive to light, scientists are unsure how they will grow.

"It may be that the roots grow virtually in any direction while the sprouts turn toward the light regardless of the germinating seeds' original position," says Tremor.

"We've never been able to maintain a zero-gravity environment long enough to run such a test, so it's hard to say what we expect. However, the Russians have reported that shoots and roots grown under weightless and dark conditions have grown along the lines determined by the seeds' original placement on the medium."

Cowles hypothesizes that plants growing in space will respond to the lack of gravity by manufacturing less lignin.

Shuttle's SRBs May Serve as Unmanned Space Vehicles

NASA scientists are considering a new role for the reusable solid rocket boosters (SRB) that lift U.S. Space Shuttles from their launch platforms. The role will be as an unmanned vehicle — the SRB-X — designed to augment Shuttle missions.

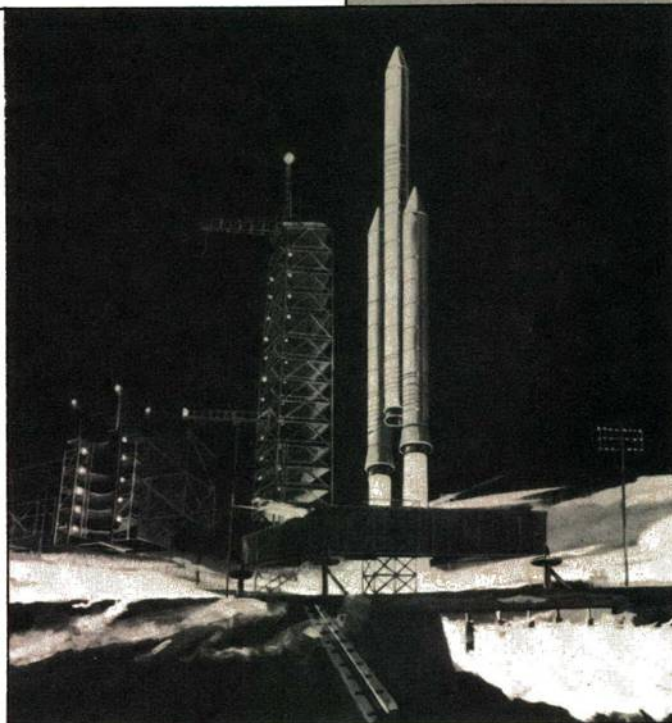
A "request for proposal," issued nationwide by the Marshall Space Flight Center in Huntsville, Alabama, invited interested firms to outline their ideas for an unmanned launch vehicle that would use the Shuttle's solid rocket boosters and motors as its principal components.

Boeing Aerospace of Seattle and Martin Marietta Aerospace of Denver have both responded to the request.

After evaluation of the responses, the Center will award a 12-month contract valued at \$250,000.

The contract will be divided into two six-month study areas. During the first half-year period, the contractor will analyze the various configurations that such an unmanned vehicle might take. During the second half-year, the firm will define in greater detail the options that seem most promising.

NASA has assigned management responsibility of the SRB-X study to the Marshall Center, since it is responsible for the Space Shuttle propulsion system and has specialized in the design, development and testing of NASA propulsion systems.



NASA Photo

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Standard equipment on both models includes: Electric Motor Drive, Setting Circles, 2 fully coated eyepieces (threaded for filters), 6 × 30 Viewfinder, rotating tube, provision for astrophotography.

6" Model 592: \$349⁹⁵ | 8" Model 791: \$479⁹⁵

All prices include packing. F.O.B. Costa Mesa, Calif.

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8" Model 791

Electric Motor Drive System

(115v./60Hz)—With fully automatic clutch: operate the telescope manually at will; the motor drive automatically engages when manual contact is released. Drive is housed in dust-proof case and supplied with outdoor-quality 6 ft. cord and safety 3-prong grounded plug.

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ASTRONOMY REVIEWS

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Simon Mitton

191 pages, hardcover, \$14.95

Scribner's (1981)

Mitton's *Daytime Star* is a thorough book written in easy-to-understand language and aimed at filling a gap that has long existed in solar astronomy. It is an up-to-date account of the history of solar observation, the instruments used by solar astronomers, what we know about the Sun, and the problems and questions we need to solve in order to better understand our nearest star.

The opening chapter recounts the history of solar observation and traces its roots through various civilizations which studied and/or worshipped the Sun. Included is an excellent description of Stonehenge, the most famous ancient solar and lunar observatory known. Mitton tells how this great configuration of stones probably helped its neolithic builders track the motions of the Sun and Moon. He also discusses the solar observatories of the ancient Egyptian and Mayan cultures.

Having grabbed the reader's attention at the outset, Mitton, in the next chapter, provides a foundation of facts on the Earth, Sun, and solar system. He describes the scale of the solar system, the Earth-Sun distance, mass of the Sun, and lays the groundwork for the rest of the book.

Chapter 3 tells how the reader can take a telescope and become a backyard solar observer, projecting the Sun's image and following the daily growth and decay of sunspots. Then, shifting focus somewhat, Mitton tells his reader about the Sun's immense energy output at all wavelengths and describes the instruments professional observers use to monitor solar activity. Included are discussions and diagrams explaining the McMath, Big Bear, and

Mount Wilson solar telescopes.

Next, opening a discussion of spectroscopy, the author introduces the Fraunhofer lines in the Sun's spectrum and describes how a solar spectrometer analyzes the Sun's chemical composition at various wavelengths.

"Architecture of the Sun" provides an outline of the solar structure by taking the reader on an imaginary trip from the center of the Sun out to the Earth. Along the way, the reader learns about the intricately balanced relationship between temperature and pressure which holds the Sun together. This chapter is brief, but it presents the Sun's inner workings to the reader and sets the stage for subsequent chapters concerning solar composition.

"The Alchemists Crucible" explains the nuclear reactions in the Sun that convert mass into energy, and describes how that energy is released to the solar system. Chapter 6 talks about the problem of solar neutrinos, and Raymond Davis's ingenious "neutrino catcher" in an old South Dakota gold mine. Mitton discusses how the neutrino telescope works and speculates about why we have been unable to observe the predicted number of neutrinos. Suggesting that our best models of the solar interior are probably incorrect, he extrapolates a bit and develops the idea that Earth could be headed for a new ice-age.

The next three chapters are the heart of the book. "Lifespan of Our Sun" presents theories, facts, and data collected over the past several decades. It outlines how the Sun could have formed, what kind of star it is, how it compares with others, its position on the H-R diagram, and how the Sun will probably die.

"Surface and Atmosphere" and "Activity and the Solar Cycle" are paired in describing the effects of

magnetism in the Sun and the accompanying phenomenon of sunspots. Mitton goes into great detail, recounting the story of sunspot observation through history and our attempts over the past few centuries to explain them. He also takes a crack at explaining the mystery of solar sunspot cycles — there seem to be several — and what sunspots could mean to Earth's climate history.

The book's final three chapters relate the Sun's effects on the solar system, and in particular on the Earth. Chapter 10 provides a look into the realm of the solar wind, with emphasis on its composition and interactions with the planets.

Chapter 11 shows how the Sun directly affects Earth's magnetosphere, atmosphere, and climate. Mitton describes the complicated interactions of solar particles with our planet's own magnetic fields and how the Earth's ionosphere shields us from harmful radiation. He also takes a look at current studies which have suggested the Sun is actually a variable star and summarizes the relevant climatic evidence of past millennia.

Chapter 12 concludes the book with a look at solar energy as an alternative to fossil fuels. Mitton speculates about its uses and reiterates the popular statement that solar power must sooner or later be taken seriously and developed into an inexpensive and practical source of energy.

Throughout the book, Mitton demonstrates the complexity of the solar surface, atmosphere, and interior. With his excellent use of a conversational approach, he has done a fine job of relating current theory and hard fact about solar astronomy at a popular level. Good photographs and diagrams feature prominently in the book and enhance the text material.

Daytime Star is a timely look at a timely subject — recommended for all

levels of astronomers and the general reader. *Dan Koehler.*

Observing Visual Double Stars

Paul Couteau

257 pages, hardcover, \$19.95

MIT Press (1981)

Here's one of the most important books ever published for the dedicated stargazer — and in an important branch of observational astronomy. Translated from the 1978 French edition by Canadian astronomer Alan Batten, *Observing Visual Double Stars* has arrived at a time ripe for a revival of this field.

Three significant but often overlooked facts make observing double and multiple stars a valuable pursuit. First, it offers the only chance astronomers have to directly measure stellar masses. Second, only a lonely handful of professional astronomers — less than a half-dozen worldwide — are now observing doubles and multiples. These few observers face the task of keeping watch on more than 65,000 pairs now cataloged. Finally, anyone with a well-mounted 5 or 6-inch telescope of good optical quality can make a contribution to double star astronomy.

Couteau's book is more up-to-date and useful to the amateur observer than Robert Aitken's classic *The Binary Stars*, and more useful and stimulating than the recent Webb Society *Deep-Sky Observer's Handbook* (Astronomy Reviews, January 1980).

In eight chapters, Couteau covers everything a telescope owner needs to know about double star observing. Topics range from the history of discovery and observations through the varied techniques of micrometer measurement to data reduction and orbit computation. The treatment they get is sound and — within the natural limits of an introductory book — comprehensive. Especially valuable is a catalog of 744 pairs of stars suitable for small telescopes which contains the latest available position angles and separations for each object.

Couteau's openly-expressed fascination and love for observing — something traditional with French astronomy writers — is impressive and shows up well in the following excerpt:

"The study of double stars requires continual observation, followed for centuries. It exceeds the term of a human life, but not of a group that dedicates itself to some task and remains stable for a long time. . . There are groups of the kind needed, in

monasteries for example . . . Astronomy is a typical monastic activity. It provides food for meditation and strengthens spirituality."

Not only does *Observing Visual Double Stars* urge you to join these dedicated observers, it also gives you a sense of purpose and urgency about your nightly vigils. Even now, many close binaries are passing unobserved through critical phases of their orbits — potentially priceless data lost for lack of observers.

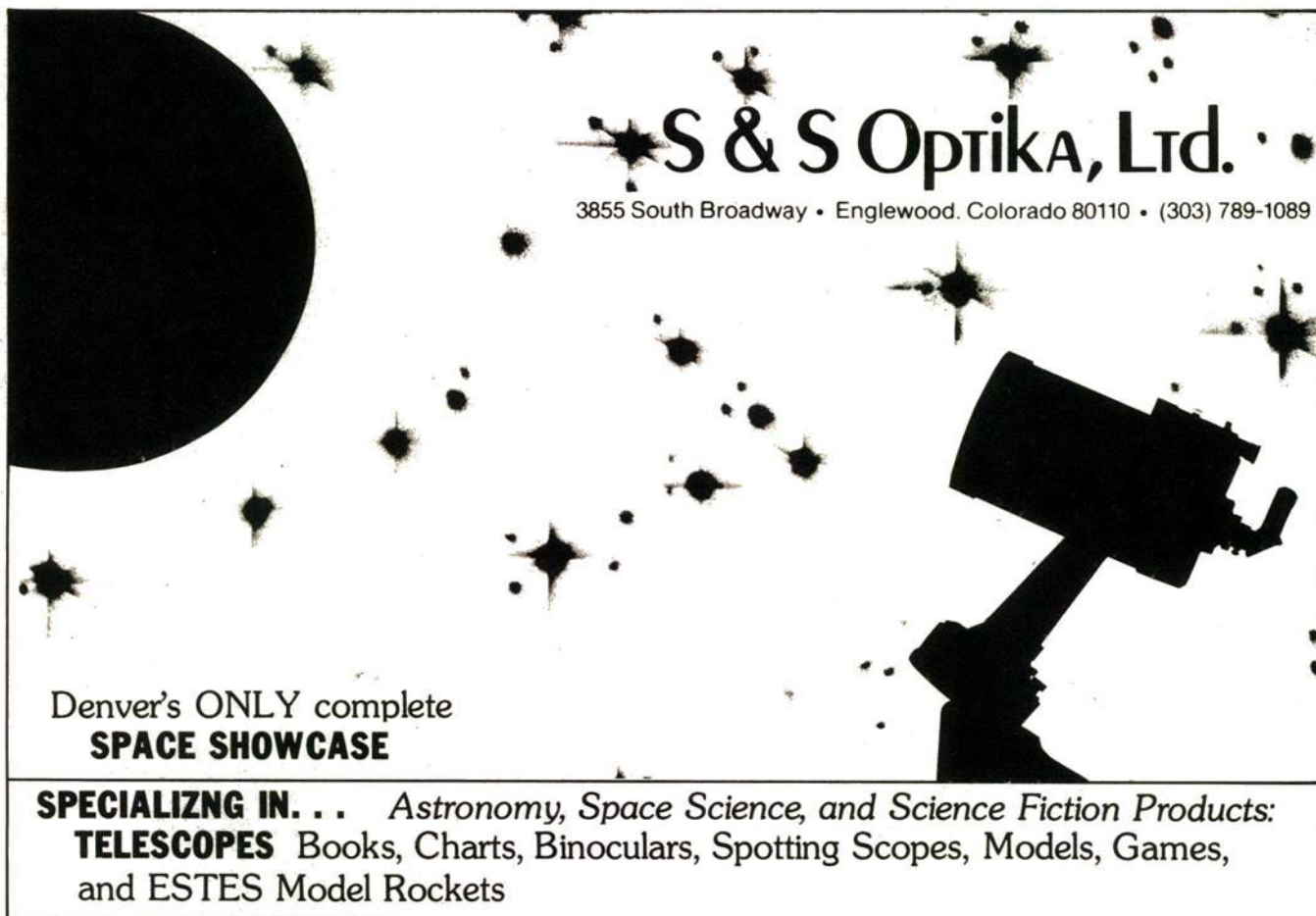
The rallying cry of double star observers was sounded a century ago by Sir John Herschel and Sir James South: "Remember, the stars will not stand still!" Shall we not heed their plea — with Paul Couteau's help? *James Mullaney.*

Multi-Ring Basins

Lunar and Planetary Institute, compilers

295 pages, hardcover, \$35
Pergamon Press (1981)

"Multi-ring basins underscore the heritage of catastrophic impacts that profoundly affected early planetary geologic history," writes science editor Peter Schultz in the preface to this volume of papers given at a



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conference in November 1980. He emphasizes that basin-creating impacts establish major stratigraphic units and long-lasting volcanic eruption centers.

The Telescope

Louis Bell
287 pages, paperback, \$5.50
Dover Publications (1981)

First published in 1922 and long out of print, *The Telescope* has been fetching a good price among used book dealers. With the arrival of Dover's reprint, you can now own an inexpensive copy of this fine work on the design and construction of telescopes, their mountings, and accessories. Jay Pasachoff has written a new introduction that summarizes the development of telescopes since Bell's day.

The Coattails of God

Robert M. Powers
288 pages, hardcover, \$15.95
Warner Books (1981)

Powers takes a close and critical look at technologies that could open up interstellar flight. After discussing various pros and cons, he proposes his

design for a multi-generational starship to be sent to Epsilon Eridani.

Relativistic Cosmology

Jean Heidmann
168 pages, paperback, \$24.80
Springer-Verlag (1981)

Subtitled "an introduction," this translation of a French book published in 1973 is intended for those who are thoroughly comfortable with undergraduate physics and mathematics.

Astronomy

Dinah L. Moche
284 pages, paperback, \$7.95
John Wiley (1981)

This is the second edition of a popular-level "self-instructor" book in astronomy. The author teaches at Queensborough Community College of the City University of New York.

The Practical Astronomer

Colin A. Ronan
153 pages, hardcover, \$20
Macmillan (1981)

Ronan's book approaches the subject of astronomy by involving

readers in simple experiments; it also serves as a reference book for backyard observers with small telescopes.

Almanac for Computers 1982

LeRoy Doggett and Joanne Seeberger
97 pages, paperback, \$5
U. S. Naval Observatory (1981)

With the *Almanac for Computers* and a calculator or home computer, you can calculate the positions of the Sun, Moon, and planets at any time during the year — and much more. Order from the Nautical Almanac Office, U.S.N.O., Washington, DC 20390.

The Grand Tour

Ron Miller and William K. Hartmann
192 pages, hardcover, \$19.95;
paperback, \$9.95
Workman Publishing (1981)

This may be the best bargain yet in space art. With over 100 paintings by artist Miller (most in color), an accompanying text by astronomer Hartmann, and a good selection of NASA photographs, *The Grand Tour* easily earns its subtitle, "a traveler's guide to the solar system."

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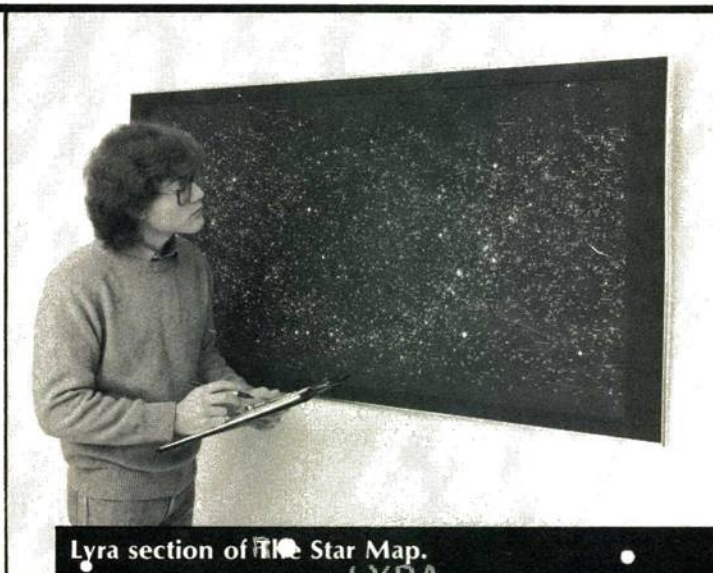
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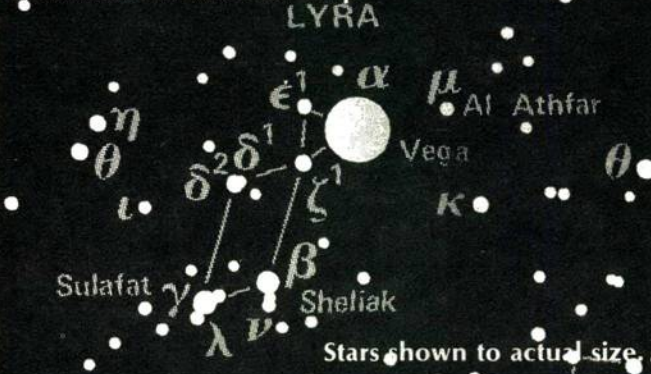
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Lyra section of **The Star Map**.



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NUMBER ONE IN A SERIES OF TECHNICAL COMMUNICATIONS (OPTICS, PART 1)

1

WHY CELESTRON® OPTICAL QUALITY IS UNBEATABLE

This is the first of a series of bulletins which will explain the design philosophy and some of the technology that has propelled Celestron International from a specialized manufacturer of large custom telescopes and research optics to the world's largest manufacturer of select modern telescopes. Why do we present this material? Celestron International remains committed to providing you, the consumer, with not only the best telescope value available, but also to provide you with the world's best customer service. Celestron has organized the world's largest network of telescope dealers to assist you in the use and selection of telescopes, with the ultimate goal of securing only satisfied customers. We encourage you to contact a Celestron dealer for information and a demonstration so that you can see for yourself the quality and versatility of the famous Celestron telescope—the best telescope value today.

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That Celestron's Schmidt-Cassegrain optical design is the best optical system for general amateur astronomy is practically unquestioned: *tens of thousands* have been delivered to individual amateurs, specified by astronomy clubs, ordered by schools and utilized in university research and industry. It is the best selling modern telescope in the world. The Celestron Schmidt-Cassegrain system must be good; it has been imitated by competitors and it is the standard against which all newcomers attempt to compare themselves. Celestron would like you to know that, among all telescopes offered to you today, Celestron still manufactures the best Schmidt-Cassegrain telescopes and that Celestron optics are still, by far, the best in terms of being better corrected for aberrations (overall optical quality) in the manufacturing process. We could say repeatedly that we're the best, and we could take you to our testing devices and show you the difference, but that may not be understandable or convenient to the average telescope buyer (how easily could you trot down to Torrance to see our demonstrations and products?). But the real evaluation of Celestron quality comes from a third party—our past or current customers. Ask our telescope owners, ask educators and planetarium staff and ask telescope/camera dealers—they'll tell you that Celestron stands alone as the best quality and best value in telescopes on the market!



Celestron 8 Telescope

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A question that any optical manufacturer must ask is: What is good optical quality and how do I assure that I'm producing a good product? The standard of optical quality long recognized by the amateur astronomical community is the "Rayleigh Criterion" which states that if the optics of a telescope have errors (physical departures in the shape of the optical surfaces) that yields a wavefront (the wave-like condensing of the light to form an image) of less than or equal to $\frac{1}{4}$ -wavelength different from that produced by a *theoretically* absolutely perfect objective, *then* the image that will be produced will be essentially perfect. Hence, when your telescope has $\frac{1}{4}$ -wave optics, you should have usable optics whereas better optics have physically measurable errors smaller than $\frac{1}{4}$ -wave; such as $\frac{1}{8}$ or $\frac{1}{16}$ -wave. Celestron International warrants its optics to be $\frac{1}{16}$ wave—optical quality far above what is necessary for enjoying your telescope.

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Celestron goes beyond simple manufacturing practices and *assures* optimum uniformity and performance by the labor-intensive task of hand-figuring each optical system in its astronomical telescopes. Celestron, and Celestron alone, to the best of our knowledge, is the only Schmidt-Cassegrain manufacturer that always hand-figures each optical system it makes. Other manufacturers, to the best of our knowledge, use methods that introduce substantial variation into the figure (the optical shape). What is hand-figuring? This "matching" procedure employs a highly skilled optician to place optics on a double-pass autocollimator (a test device) and utilizes four tests: inspect the Airy disk, test for spherical aberration by inspection of the out of focus diffraction images, the Ronchi test, and a null or knife-edge test. Based on the interpretation of these tests, the optician custom manufactures a pitch lap for one of the elements of the particular optical system under examination and gently hand polishes any irregularities out of the system. This process is repeated until a smooth optical figure free of localized optical errors (zones) is produced. You are invited to see our quality control station should you ever visit our Torrance, California factory. We think you'll find that no other manufacturer is so open in explaining and demonstrating its products or so proud of its accomplishments. Celestron's matching process produces a telescope that has optics that are not only of $\frac{1}{16}$ -wave, but also of exceptional *smoothness* such that an overall averaged departure of the optical accuracy is $\frac{1}{32}$ -wavelength expressed as the root mean square. This difference can be seen in optical tests as well as in actual use of the system. What does this mean to you, as an observer or photographer? Simply, higher contrast images. The smoother the optical figure, the *fewer* small abrupt surface changes there are on the optical surfaces, the better defined the images the telescope can deliver (technically less light is diverted outside the diffraction disk).

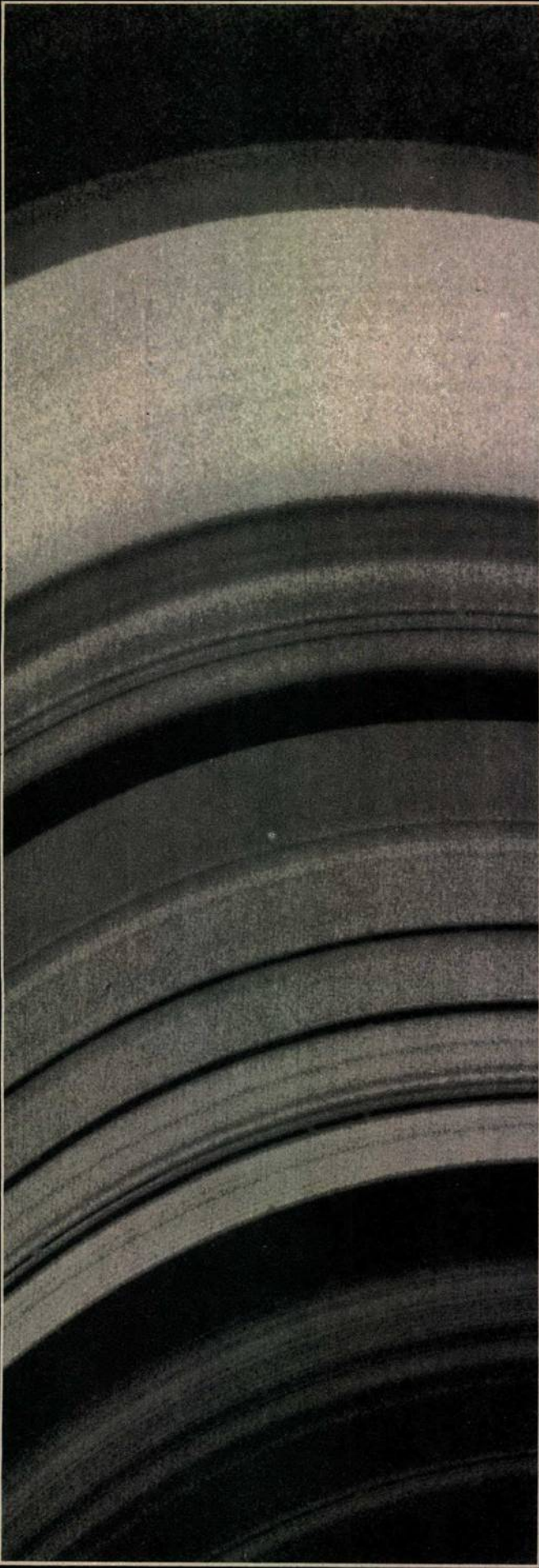
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The Celestron 8 will demonstrate nicely its high optical quality when you conduct a side-by-side inspection with competitive Schmidt-Cassegrain telescopes. When you inspect a stellar image, you'd find the Celestron's would be closer to the theoretical "diffraction image" a very small round ball (the "Airy side") with a single ring around it. The images in competitive scopes would show more scattered light (the Celestron will always concentrate a greater percentage of starlight into the primary maximum or Airy disk)—the stars would not be sharp points, closer binary stars would not be as cleanly separated and details would not be as visible on low contrast objects such as the delicate festoons in Jupiter's atmosphere or the swirls of nebulousity in the Orion Nebula (M42). The optics of the other telescopes may also show such optical irregularities as astigmatism, down or upturned edge, undercorrection or overcorrection, all of which are eliminated with Celestron's unique matching.

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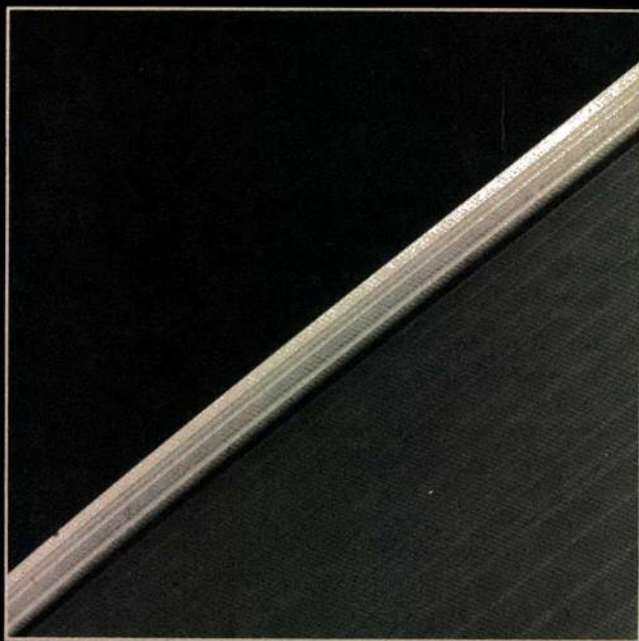
a closer look at **SATURN'S RINGS**

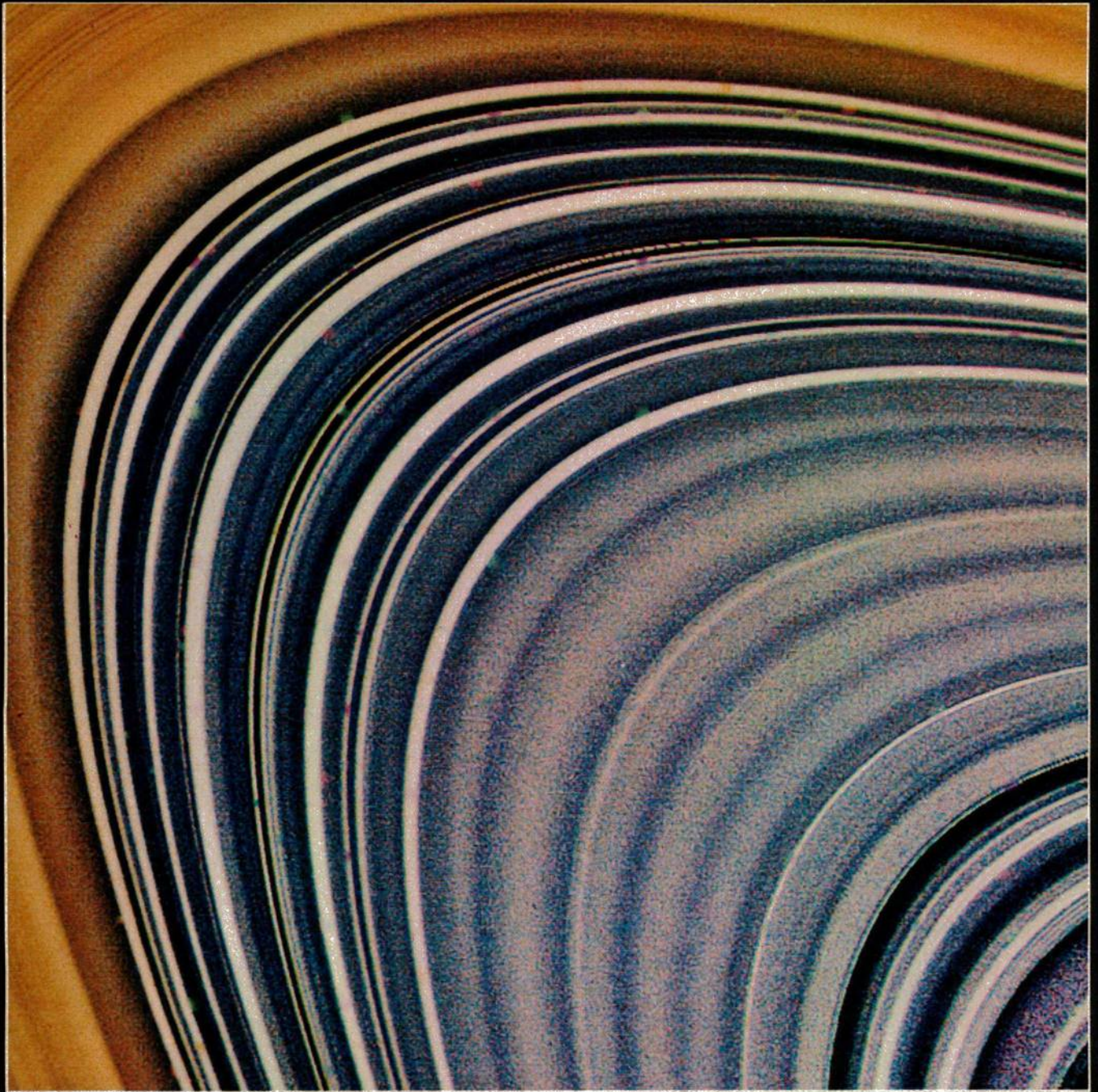
Months after the Voyager 2 encounter with Saturn and more than a year after Voyager 1, planetary scientists continue to analyze the exquisite images snatched by the two spacecraft in their dashes through the Saturn system. The Voyagers probed the details of the rings in four broad size ranges.

The largest was that of entire gaps and ringlets. These were measured by the stellar occultation experiment. Their dimensions are typically kilometers to tens of kilometers. On a finer scale, scientists probed the rings for meter-size ring particles — “particles” the size of automobiles or houses — using scattered radio energy. Another range investigated was the centimeter size range — grape to baseball size — measured by transmitted radio waves. On the smallest scale, Voyager detected tiny particles in the millimeter and nanometer range — snowflake down to smoke particle size. Scientists deduced their presence by the scattering of sunlight off the rings.

The complete set of radio occultation data obtained during Voyager 1's passage behind the rings is immense, so the complete job of “deconvolving” the ring information buried in the signals will take years. But we do have some early results: the average ring particle size in the C ring is 2 meters; in the Cassini Division, 8 meters; and in the A ring, 10 meters. The F ring contains particles about the size of a wavelength of orange light — 0.6 nanometer. Astronomers have also found that there is not just one particle size, but a distribution of sizes, and the distribution of sizes is different in different places in the rings.

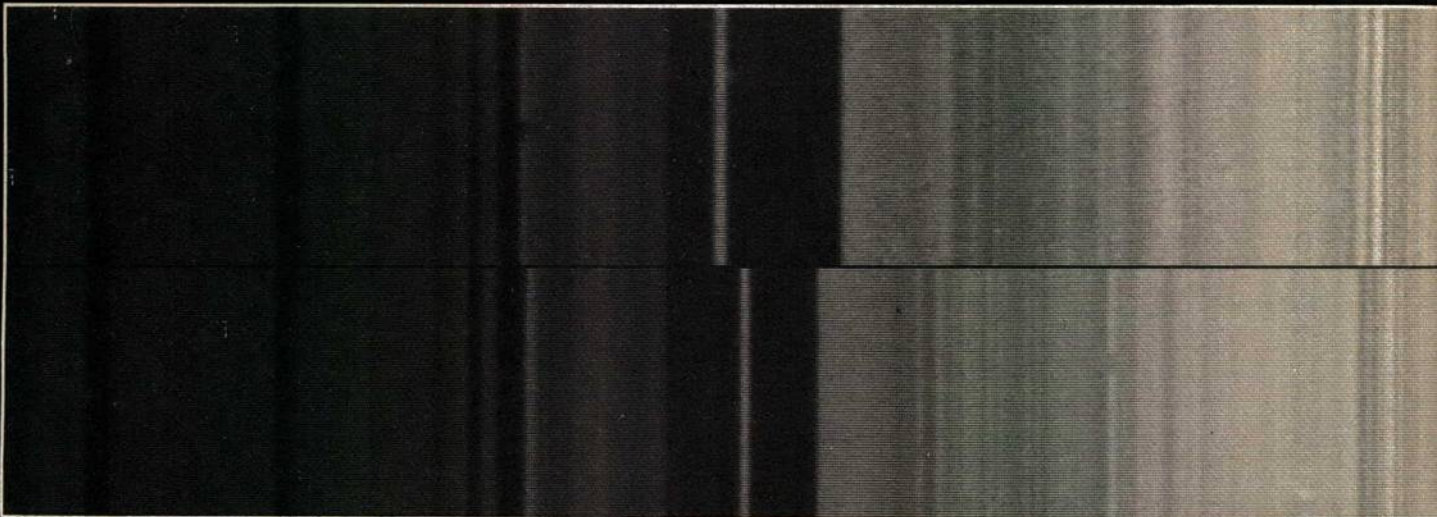
And there are odd effects — particles piling up at the edges of rings, for example. By comparing the two radio





Opposite page, left: The Cassini Division is not empty, but contains its own ringlets and gaps with gaps between them. NASA photo 260-1129. Bottom: Even at a resolution of 2.5 kilometers, the outer edge of the A ring is sharp; its thin bright rim is different from the rest of the A ring, possibly because it contains more fine fragments. NASA photo P-23965. Above: Enhanced color permits discrimination of subtle composition differences in the rings. The C ring is predominately blue — the B ring yellow. Note, however, several narrow yellowish ringlets within the C ring. NASA photo P-23927. Below: Voyager 2's cameras recorded the tenuous innermost ring — the D ring — in a special long exposure. The shadow of the planet falls across the bottom of the frame. NASA photo P-23967.



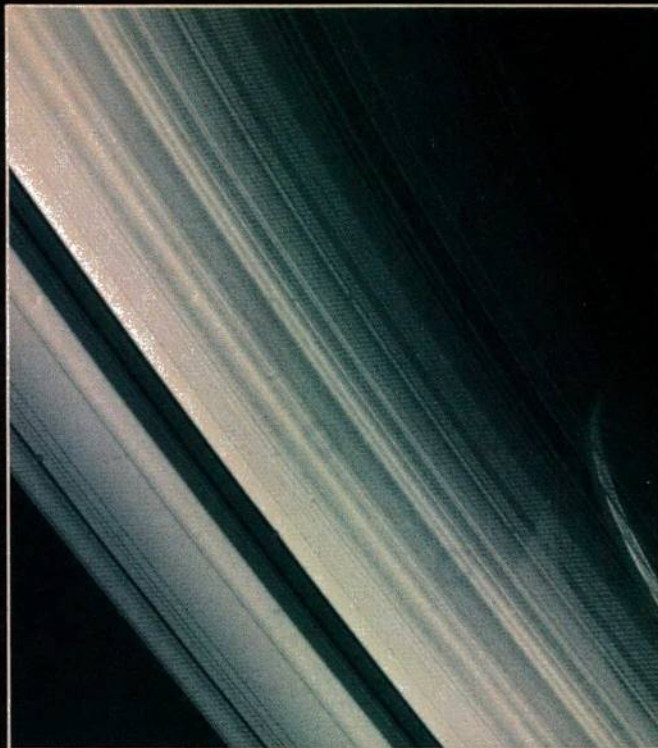


frequencies used in the radio occultation, the experimenters can separately examine two centimeter-size populations of particles — one golf-ball size and the other baseball-size. The results are astounding. In some places, the number of larger and smaller particles matches perfectly; there are corresponding numbers of both populations in ringlets and fewer of both in the gaplets between the ringlets.

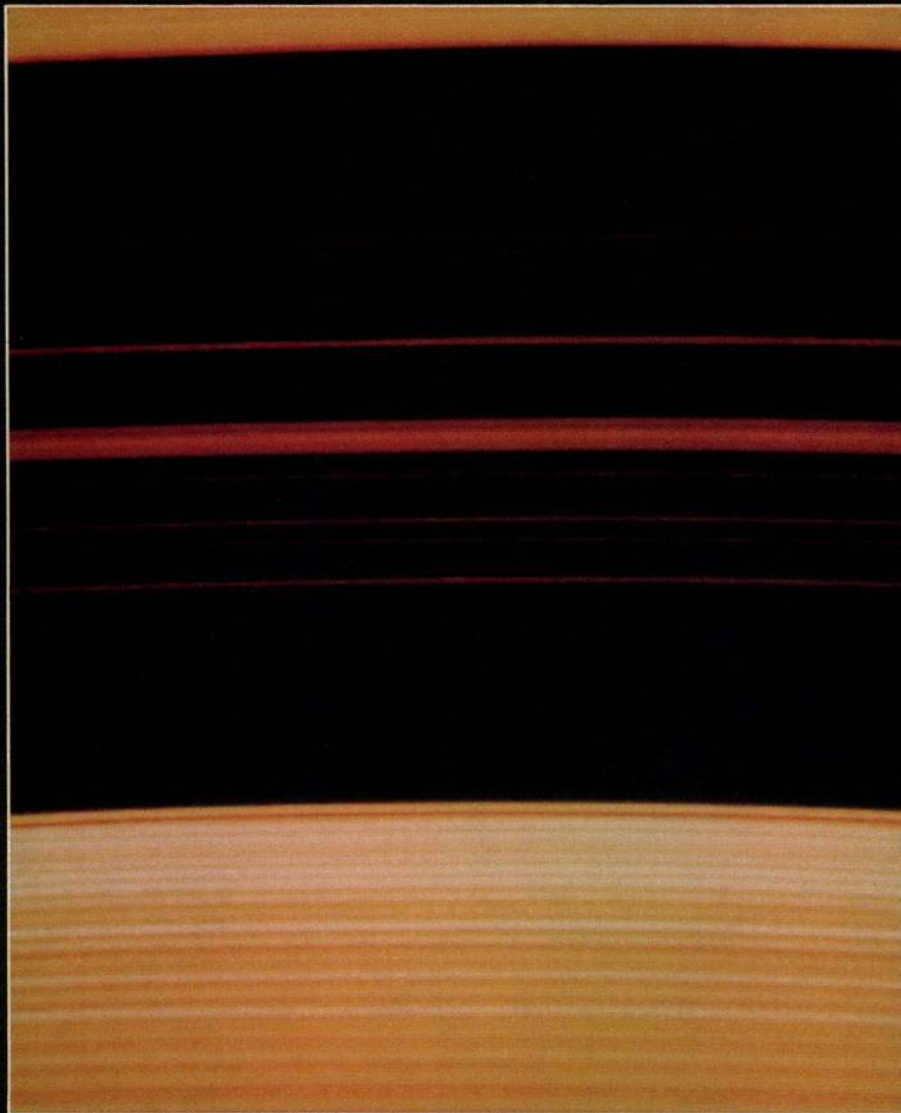
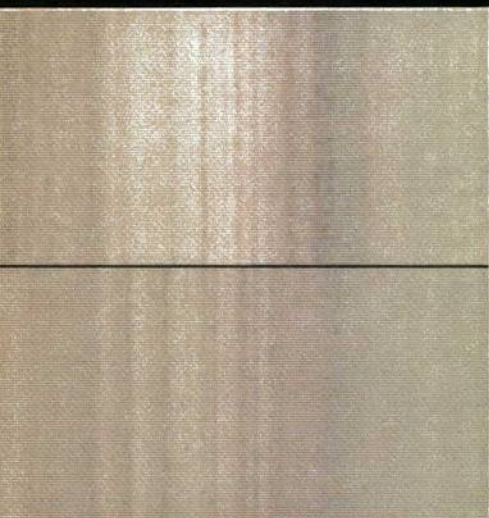
In other places, the edges of ringlets have fewer golfball-size particles than the centers, while the distribution of baseball-size particles remains constant across the ringlet. In some cases, *both* populations appear to be piled up at the edges of a ring.

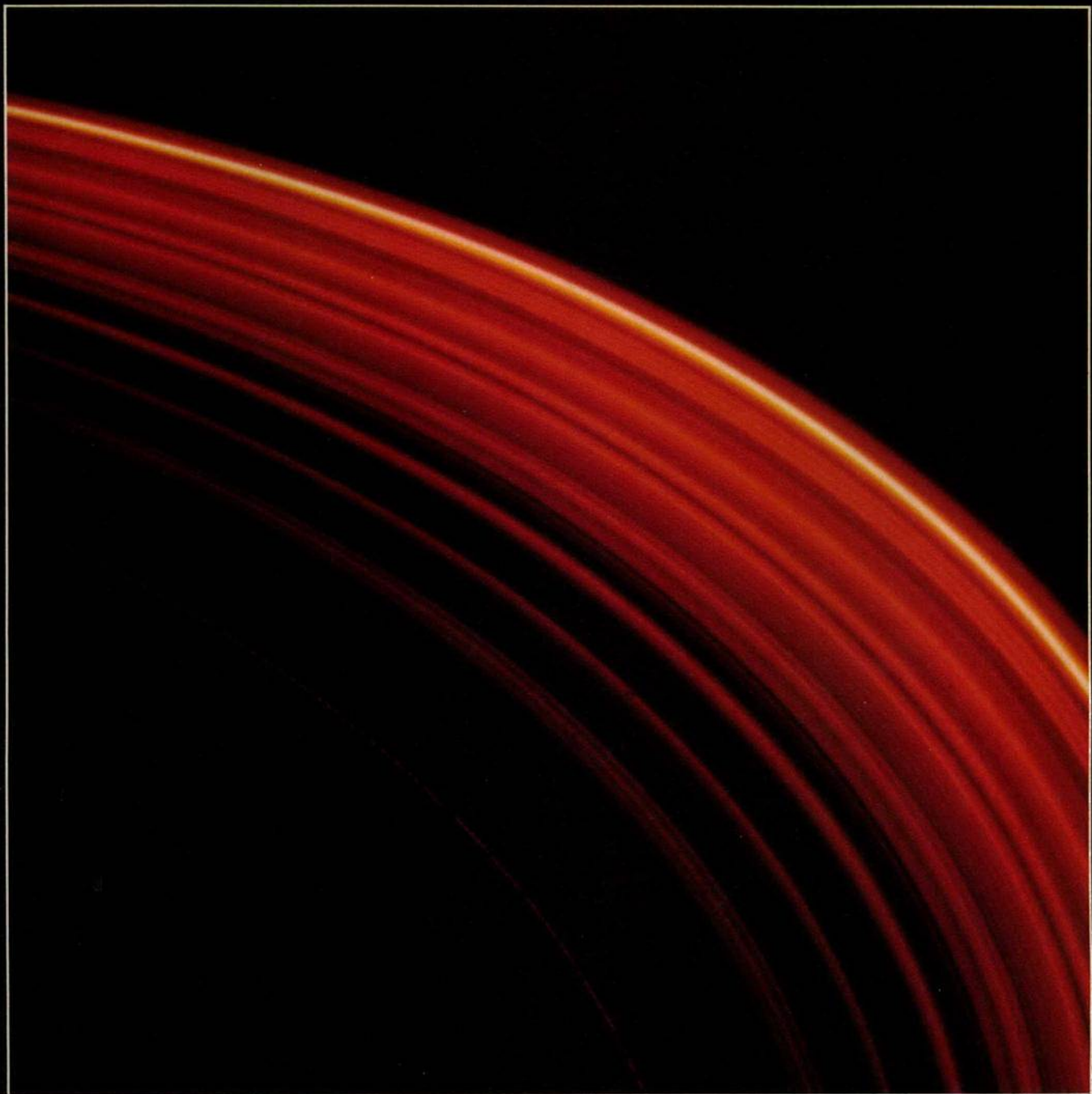
We've also learned something about the thickness of the ring system from the Voyager data. Seen edge-on from Earth, the rings nearly disappear. Astronomers have long known they are under 1 kilometer — but not *how much* under a kilometer. Now the radio measurements place an upper limit to the thickness of about 400 meters, and optical measurements suggest a thickness closer to 100 meters. The rings are apparently only a few particle diameters thick in the regions where meter-sized particles predominate.

The edges of the rings are strangely sharp. Although they logically could taper off to nothing over tens of



Opposite page, top: The shadow of the thin C ring falls on the bland equatorial regions of Saturn. NASA photo P-23928. Below: In this comparison of images of the inner edge of the Cassini Division taken on opposite sides of Saturn, rings and gaps are mismatched because of the perturbing effects of Mimas. NASA photo P-24064. Above right: Saturn's limb shines through the C ring and part of the B ring. The bright line on Saturn is light passing through the Cassini Division, which appears as a dark band. NASA photo P-23931. Right: Traced by the photopolarimeter at a resolution of two kilometers, the Encke Division has a thin central ringlet, and the A ring shows regular gravitational waves. NASA photo P-24069.





Above: At resolutions of a few hundred meters, the brightest strand of the F ring breaks up into dozens of strands over a distance of 55 kilometers. NASA photo P-23960. Left: Beyond the main rings, and beyond the F ring (bright band just off A ring), is the extremely faint G ring. NASA photo P-23968. Opposite page, top: At very high resolution, the shadow of Saturn on the A ring is soft-edged. Note the bright irregular ringlet on the inner edge of the Encke Division. This is the "kinky Encke" ringlet. NASA photo P-23963. Middle two: The Encke ringlet is not one, but two discontinuous ringlets. NASA photo P-23952. Bottom left: Voyager 2's cameras showed four or five strands in this unbraided section of the F ring. NASA photo P-23966. Bottom right: This Voyager 1 image of the F ring shows braiding. NASA photo P-23099.

kilometers, radio occultation measurements place an upper boundary of 5 km on the diffuseness of several sharp ring edges. But optical measurements show still sharper transitions — only three kilometers separate free space from densely-filled ring at the outer edge of the A ring!

The kilometer-scale structure of rings and gaps measured by the stellar occultation experiment also shows strong evidence that gravitational resonances with satellites do occur — notably in the resonance with the leading co-orbital satellite. The disturbances in the ring structure propagate outward for about 500 kilometers. The 2:1 resonance with Mimas coincides with the outer edge of the B ring, and that edge shows an eccentricity of 150 kilometers. The embedded moonlet theory — a theory which offered an easy-out for theoreticians attempting to explain the Cassini Division — has fallen flat on its face. Voyager's cameras showed no embedded moons down to 10 kilometers in diameter, and quite likely none to a considerably lower limit.

Meanwhile, as the investigations of forces that may drive the rings get under way, astronomers are heading for the largest computers they can get their hands on — and finding out what really does happen when they try the mind-boggling mathematics of a million million million independent moonlets in a ring system. Initial computer runs show kink-like bunchings of ring particles that come and go — offering hope that the braided F ring and the kinky Encke ring no longer present an intractable problem in celestial dynamics.

— Richard Berry



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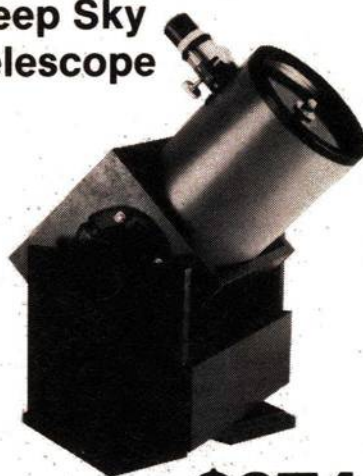
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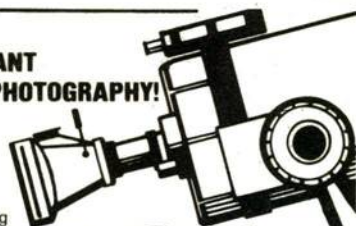
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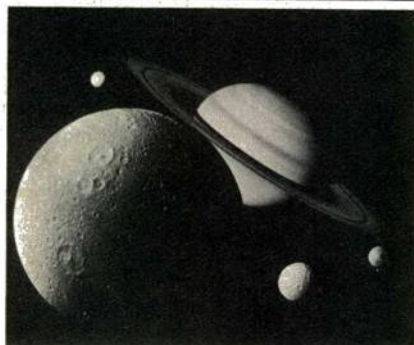
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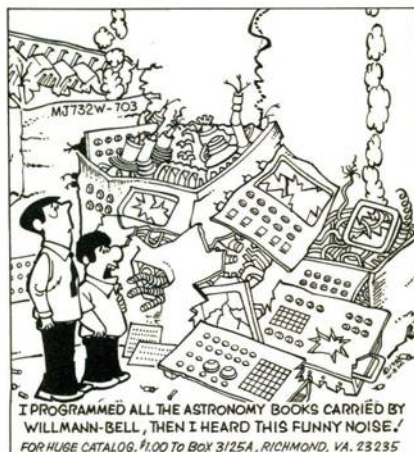
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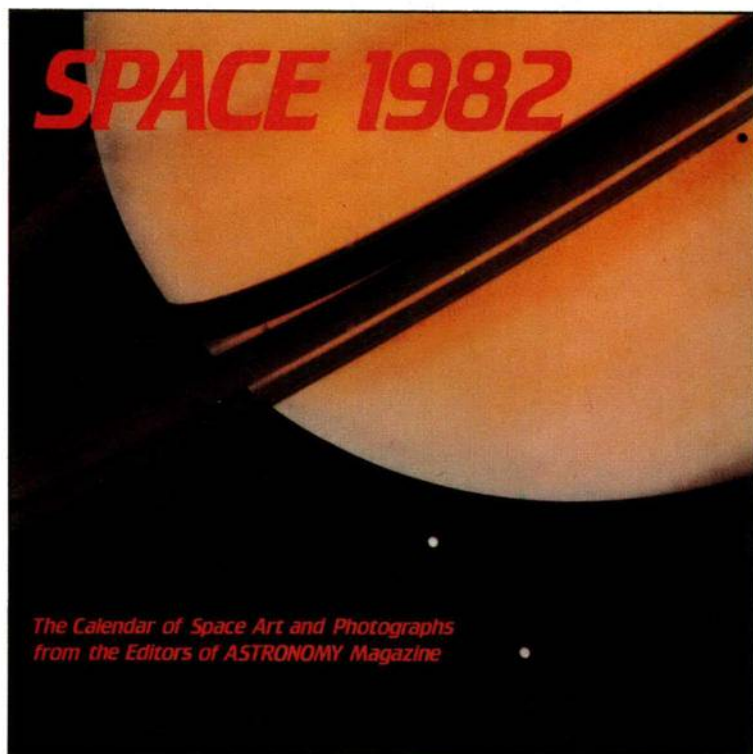


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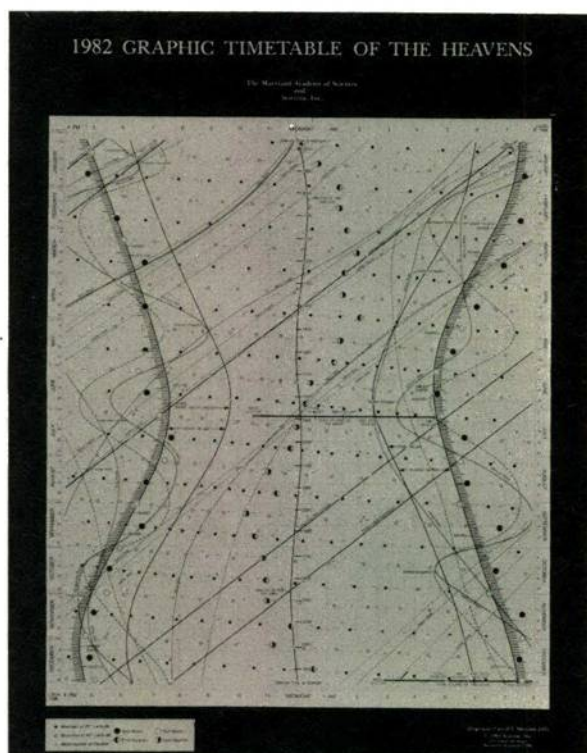


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The 1982 Graphic Timetable of the Heavens displays the motions of all major solar system bodies for the entire year. You'll know when the Moon and planets rise and set; when conjunctions occur; and when eclipses, transits, elongations, solstices and lunar phases take place. The easy-to-follow grid allows you to pinpoint all these heavenly bodies for any date and time.

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In the enormous emptiness of our local Universe there are one hundred billion stars: A star for each human being that has ever lived! Is there anyone out there...or are we alone? No one knows, but we can begin to look for signs of extraterrestrial intelligence by eavesdropping on the radio communications that they may use.

NASA's Search for ExtraTerrestrial Intelligence (SETI) Program is designed to do just that, but the Political EaRTh Intelli-

gence just cut all the funds for SETI research. Are we intelligent enough to conduct a SETI program? Delta Vee, home of the Viking and Halley Funds, thinks so, and in response to public demand announces its Extraterrestrial Connection (DVEC): a public fund aimed at financing NASA's SETI program. Delta Vee, using its Viking Fund precedent, will contract with NASA for actual SETI observations of stars and for the upgrading of data processing equipment.

HELLO?

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the backyard astronomer

gemini

After February 1, all the major planets — naked-eye and telescopic — will be in the morning sky. Accordingly, sky watchers will have to brace themselves and, in the northern latitudes at least, bundle up. February mornings are *cold*. But the sky show in the hours before morning twilight begins will be spectacular, so you won't want to miss it.

Mercury

After Mercury passes inferior conjunction at 4h UT on February 1 (23h EST, January 31), it will hasten to the west of the Sun and reach greatest elongation on February 26. Although the angular separation is a fairly wide 27° , this elongation won't achieve a very high elevation — a maximum of about 5° from the 15th to the 23rd. By the time of actual elongation, Mercury's altitude will have slipped slightly to about 4° .

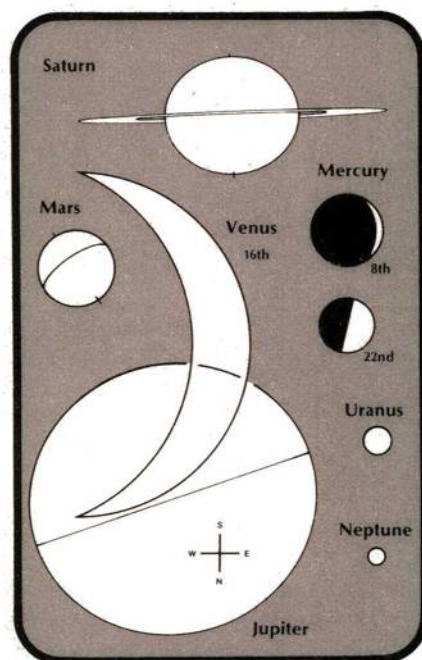
Remaining generally in the east-southeast, Mercury's azimuth will range from 110° at its first appearance — about a week after conjunction — to 119° on the 21st, and then back to 110° again by the time it disappears from view around March 10.

Venus

Venus also hurried through inferior conjunction and is now a morning object that will reach greatest brilliancy (magnitude -4.3) on the 25th. Although Venus is just as bright as it was in the evening sky, it won't be as high or as conspicuous for northern hemisphere observers because at this time of year the ecliptic — the path the planets follow — lies at a shallow angle to the eastern horizon just before

sunrise. (This also explains why Mercury's elevation is so low, despite a fairly wide elongation.) See the diagram on page 90 for Venus' path during the rest of its 1982 apparition.

Despite Venus' low elevation, most telescopes will show its changing phases very easily. Our sister planet will retain its crescent shape all month, and will shrink from about $60''$ of arc



on February 1, to about $39''$ of arc by the 28th. During that time, the illuminated portion of its disk will increase from 5% to 28%.

Mars

Situated in Virgo several degrees to the northwest of Spica, Mars is a prominent object in the midnight sky. It is easy to distinguish from Saturn and Spica, because it is brighter and more orange-colored than those objects.

Having passed its aphelion on January 12, Mars' northern

hemisphere starts its summer on February 24. The Sun will then be directly over latitude $+24^\circ 42'$. The coincidence of summer solstice at aphelion creates a chilly summer for the martian northern hemisphere and a biting cold southern hemisphere winter. As a result, Mars' southern polar ice cap is by far the thicker of the two.

It's fun to look for the dark features on the ball of the planet — to most people they look grey or greenish-grey — and since the martian day lasts only some 40 minutes longer than ours, you'll see evidence of rotation if you observe for an hour or two.

Another feature to look for is more transient: the martian atmosphere often shows clouds and hazes — especially near the sunset (western) limb where temperatures drop sharply. Many observers have found that a blue filter makes clouds more obvious.

Asteroids

1 Ceres (magnitude 7.9) is in northern Libra. Its positions:

10th: 15h 22m 49s, $-9^\circ 15.6'$

20th: 15h 31m 15s, $-9^\circ 35.3'$

Ceres rises about 1 a.m. local time at mid-month.

2 Pallas (8.0) lies in Virgo, near and to the west of the 3rd magnitude star, Zeta (ζ) Virginis — which it approaches most closely on February 18 at a distance of $33'$ of arc. Its positions:

10th: 13h 27m 37s, $-2^\circ 16.5'$

20th: 13h 30m 29s, $+0^\circ 29.1'$

Pallas rises about 10:30 p.m. local time on February 15.

3 Juno (11.4) is in Serpens Cauda. Its positions:

10th: 17h 43m 58s, $-12^\circ 06.8'$

20th: 17h 55m 01s, $-11^\circ 44.7'$

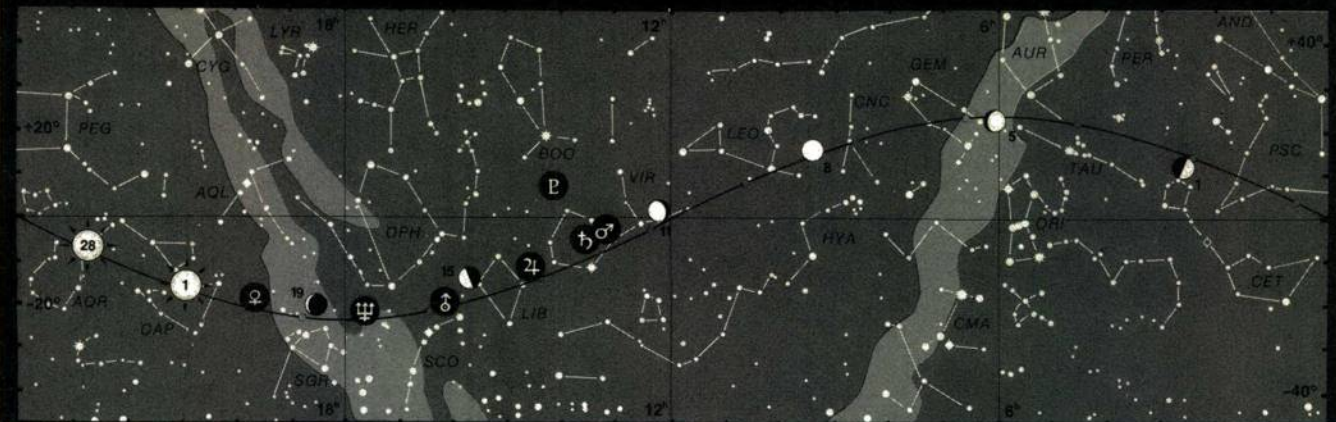
Juno rises around 3:30 a.m. local time in mid February.

4 Vesta (7.8) lies just east of the dome of Sagittarius' teapot. Its positions:

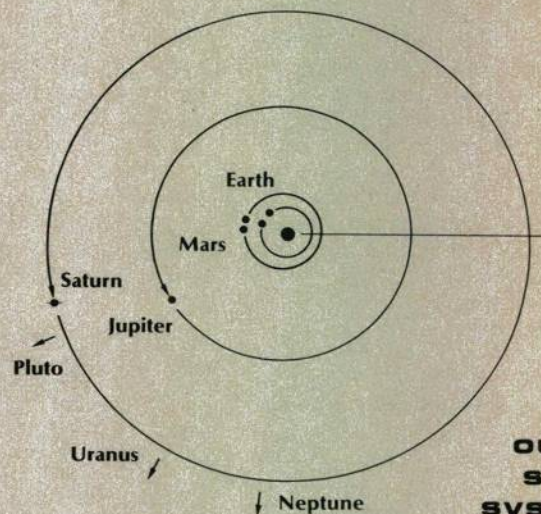
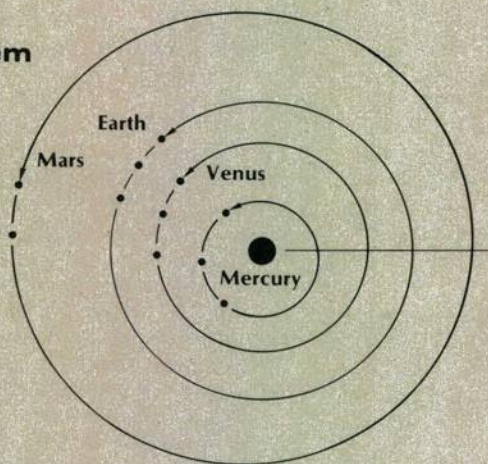
10th: 18h 35m 31s, $-21^\circ 00.5'$

20th: 18h 56m 59s, $-20^\circ 50.6'$

Nelson Chow used a 50mm f/3.5 lens and a 10-minute exposure on Ektachrome 400 to capture this very bright Perseid as it streaked across the sky above Algonquin, New Mexico. He wins February's "Best Astrophoto" award for his effort. Explosions within the meteor caused the variations in the streak.



inner solar system



outer solar system

	Date	Mag.	Angular Size	% Illum.	Distance (AU)		Longitude:		R.A. (1982.2)	Dec
					Earth	Sun	Heliocentric	Ecliptic		
Sun	1	-26.8	32.5'	—	0.99	—	—	311°48.4'	20h 57.0m	-17°15.1'
	15	-26.8	32.4'	—	0.99	—	—	325°58.9'	21h 52.9m	-12°51.8'
	28	-26.8	32.3'	—	0.99	—	—	338°37.6'	22h 40.9m	-8°19.0'
Mercury ♿	1	+2.6	10.1"	12%	0.66	0.33	131°06.6'	311°43.7'	20h 54.5m	-13°48.1'
	15	+0.7	8.6"	34%	0.76	0.41	193°47.3'	302°38.4'	20h 19.5m	-17°26.4'
	28	+0.3	6.8"	61%	0.98	0.46	234°41.2'	311°56.0'	20h 59.3m	-17°29.1'
Venus ♀	10	-4.1	51.9"	12%	0.32	0.72	152°52.3'	292°55.9'	19h 35.8m	-14°10.7'
	28	-4.3	38.7"	28%	0.43	0.72	182°04.4'	298°19.0'	19h 58.1m	-15°07.9'
Mars ♂	15	-0.1	10.8"	94%	0.87	1.66	170°36.2'	198°23.4'	13h 14.7m	-4°37.5'
Jupiter ♃	15	-1.7	38.7"	99%	5.09	5.44	210°08.5'	219°42.8'	14h 32.8m	-13°37.8'
Saturn ♄	15	+0.7	18.4"	100%	9.07	9.65	197°10.9'	201°35.3'	13h 25.5m	-6°08.9'
Uranus ♅	15	+5.9	3.6"	100%	18.98	18.86	241°25.7'	243°47.1'	16h 09.8m	-20°51.4'
Neptune ♆	15	+7.8	2.4"	100%	30.76	30.27	264°56.7'	266°01.0'	17h 45.1m	-22°07.7'
Pluto ♇	15	+13.9	—	100%	29.51	29.98	205°07.8'	206°18.4'	14h 04.5m	+5°51.8'

moon data

First Quarter February 1 at 14:28
 Full Moon February 8 at 7:57
 Last Quarter February 15 at 20:21
 New Moon February 23 at 21:13
 First Quarter March 2 at 22:15
 Full Moon March 9 at 20:45
 Perigee: February 5 at 14h 365,100km
 Apogee: February 17 at 8h 404,500km

universal time

Astronomers the world over use an unambiguous system of time reckoning — Universal Time (UT) — based on a 24 hour clock. Times in The Backyard Astronomer are UT unless otherwise noted. To convert UT into your local standard time, subtract the following number of hours for each time zone: EST, 5; CST, 6; MST, 7; PST, 8; Alaska and Hawaii, 10. For example, if an event is to happen at 03:00 hours UT on January 2, then EST for the event is 10 p.m., January 1. Likewise, 03:00 UT on March 5 becomes, in PST, 7 p.m., March 4.

This "double exposure" of Mars, taken about two weeks after its 1980 opposition, shows the bright north polar cap (at bottom). The light-colored area on the lefthand limb is part of a cloud over the Tharsis volcanos. Don Parker used a 2-second exposure at f/128 on 200 ASA film with a 12½" f/6.5 telescope.

Vesta rises at about 5:00 a.m. local time on the 15th.

6 Hebe (11.0) is moving slowly westward in northern Virgo. Its positions:

10th: 12h 28m 16s, +8° 37.9'

20th: 12h 24m 30s, +10° 10.6'

Hebe rises about 9:00 p.m. local time in the middle of the month.

(All asteroid positions are in 1950 coordinates to allow easier plotting on a star atlas.)

Jupiter

Among the most interesting observational aspects of Jupiter are the motions of its four biggest moons — Io, Europa, Ganymede, and Callisto. Since we view these moons nearly in the plane of their orbit around Jupiter (during February our direct line of sight strikes the planet about 3° south of its equator), they are perpetually passing in front of the planet and disappearing behind it.

You stand a good chance of catching them transiting the disk, disappearing into Jupiter's shadow, and then reappearing from behind its limb. You may even spot their shadows crossing the disk of the planet.

Saturn

A short distance to the east of Mars and about due north of Spica, Saturn is well up and easy to locate by late evening.

Like Jupiter, Saturn has satellite transits and occultations, but its greater angle of tilt to the Sun and to our line of sight makes such events far more rare: most of the time, the moons pass above or below the disk of the planet. Adding to the challenge, all of its moons, with the exception of Titan which is bright and easy to see, are dim, or remain close to the bright planet — or both!

Uranus

Uranus lies about 3m to 5m of right ascension due east of the two 4th magnitude stars, 9 Scorpii and 10 Sco, that together make up Omega (ω) Sco. It is also 2° southeast of the bright double star Beta (β) Sco. When you find it, you'll see a 5.9 magnitude dot of light just 3.6" across in arc.

Neptune

Every year as Neptune re-emerges from the Sun's glare in the morning sky after opposition, it lies a bit closer to the Milky Way. As a result, re-acquiring the planet becomes a little more difficult. The naked-eye star closest to Neptune is 4.9 magnitude 58 Ophiuchi. Once you find it, you'll have little trouble locating the 7.8

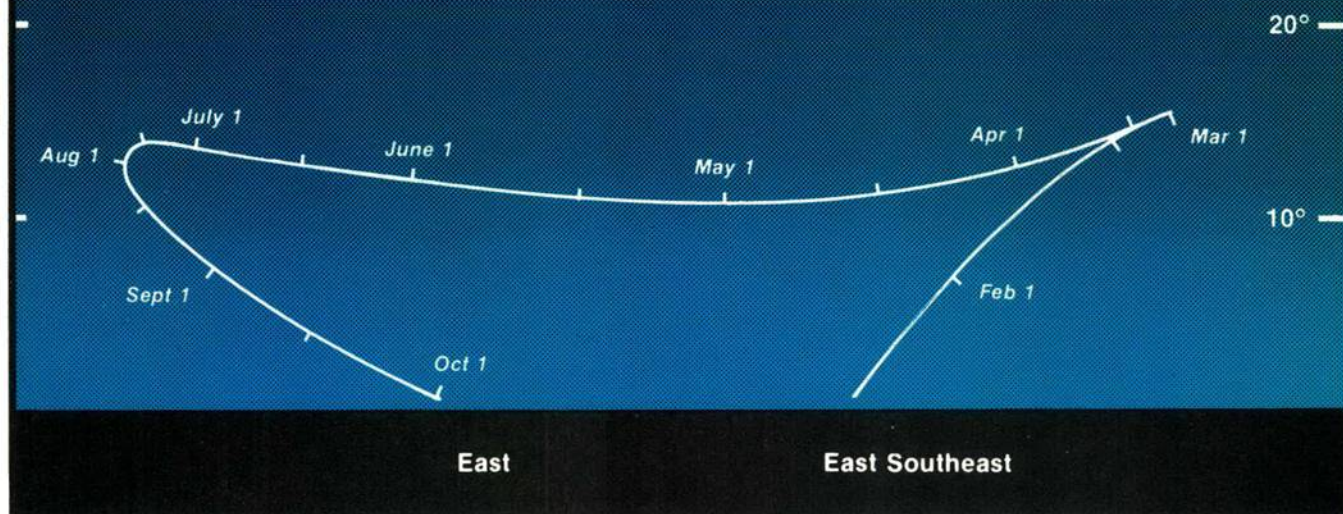


satellites of jupiter					10:00 ut				
1	403		• • •		16	23014		• • • •	
2	4230		• • •		17	340		• • •	
3	4301		• • •		18	34102		• • • •	
4	43102		• • • •		19	43201		• • • •	
5	4201		• • • •		20	42103		• • • •	
6	42103		• • • •		21	40213		• • • •	
7	40123		• • • •		22	41023		• • • •	
8	41023		• • • •		23	42301		• • • •	
9	2304		• • • •		24	34210		• • • •	
10	304		• • • •		25	3402		• • • •	
11	31024		• • • •		26	3014		• • • •	
12	2013		• • • •		27	21034		• • • •	
13	21034		• • • •		28	02134		• • • •	
14	01234		• • • •						
15	10234		• • • •						

Jupiter = 0, Io = 1, Europa = 2, Ganymede = 3, Callisto = 4
(South is at top, matching the view in a telescope)

Venus - 1982

(45 minutes before sunrise)



magnitude planet with the 2.4" of arc disk.

But how do you find 58 Ophiuchi? Fortunately, there is no other star near it with the same brightness. It lies about halfway between 4th magnitude Xi (ξ) Ophiuchi and 4th magnitude Mu (μ) Sagittarii. Mu lies about 9° north of the teapot's spout and Xi lies 16° almost due north of Shaula, the star that marks Scorpius' tail.

When you've centered 58 Ophiuchi in a low to moderate-power eyepiece, look about half a degree south-southeast of the star early in February or a degree to the southeast late in the month. The dot with the discernible disk is Neptune.

close-up on gemini

A clear February evening can bless an observer with the best of two worlds. Not only are the winter constellations still prominently placed, but a host of fainter spring constellations are invading the eastern sky and ushering in a vast realm of galaxies that will soon add to your observing pleasure.

On these nights the sky appears almost divided in two, as the bright winter stars descend, and the apparent void in the eastern sky looms ever larger in the heavens. Before we start our night of observing, take a moment to relish the quickly disappearing stars that beckoned you outside. Orion is on his way down, following Taurus and the Pleiades, but high overhead **Gemini**, the constellation of the

famous twins, still reigns.

One of the most prominent zodiacal constellations, Gemini actually looks like its namesake. The graceful curving lines of stars can conjure up visions of earthly bodies, even though they are mere stick figures in the sky. And the twin stars Castor and Pollux make identification easy, even for a beginning observer. Gemini is also a treat for the experienced observer because it is filled with treasured deep-sky objects.

Facing east, you can spot Gemini about two-thirds of the way up in the southeastern sky. The dual suns of Castor and Pollux symbolize the heads of the mythical brothers. **Castor** is designated Alpha (α) Geminorum and the name literally translates as "The Horseman." Shining at magnitude 1.6, it is actually fainter than its "brother" that lies only 4.5° away. Both stars are prevalent throughout the historical records of the ancients, and today one of them symbolizes a fascinating mystery.

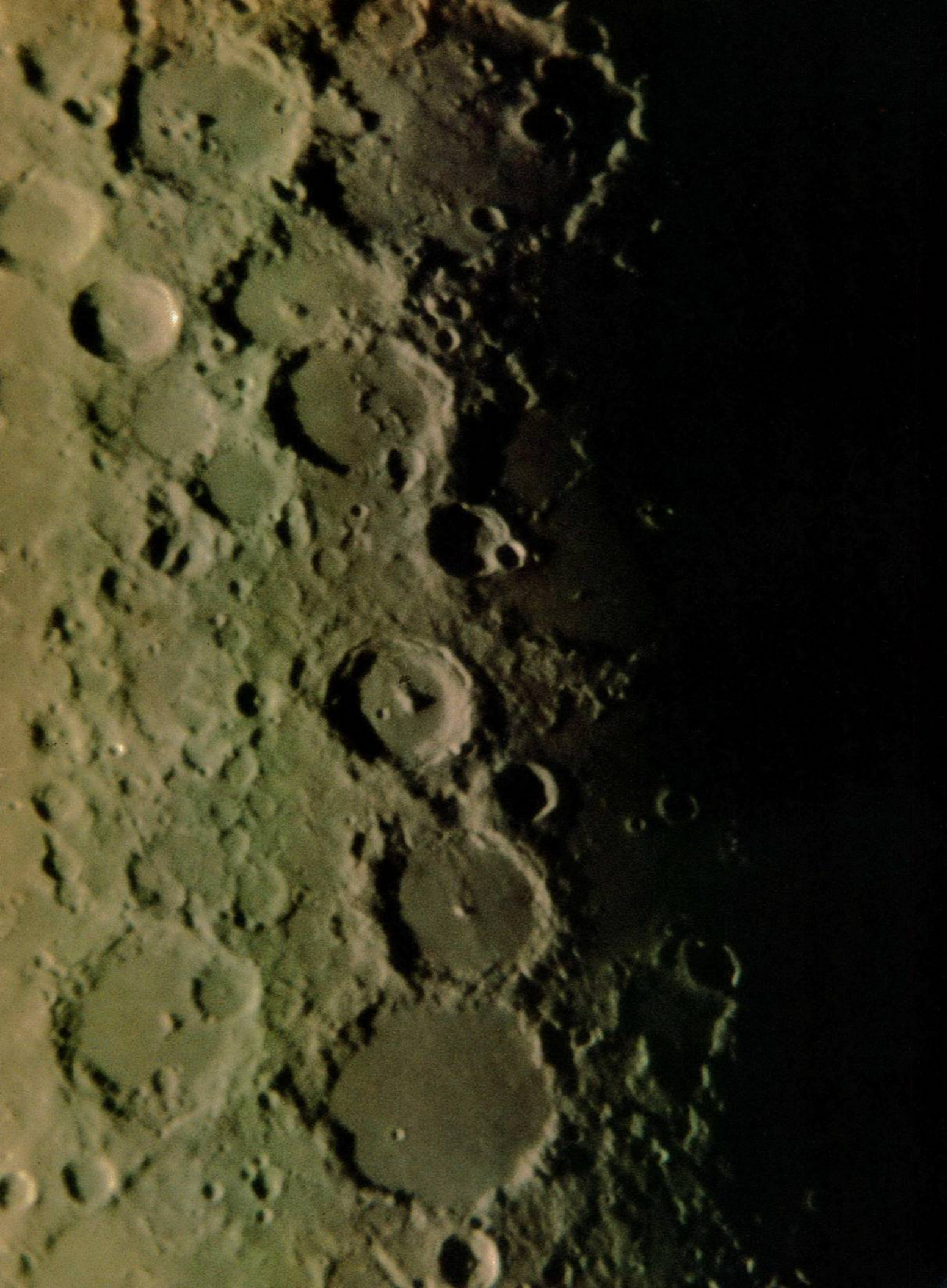
Castor lies some 45 light-years away and is 36 times brighter than our Sun. Although it appears as one star to the naked eye, Castor is actually a double and is easy to split even with a small instrument. Robert Burnham Jr. called this star the "finest double in the north sky for a fair sized glass." G.D. Cassini first discovered its binary nature in 1678, but it was not rediscovered until 1718 by J. Bradley. Visible in backyard scopes, **Castor A** and **B** are magnitudes 2.0 and 2.8 and have a period of revolution of nearly four centuries. This main pair is flanked at a great

Above: The diagram shows the path Venus will take in the morning sky from late January through September 1982. The view is from 40° north latitude. **Right:** Jean Dragesco's photo shows several large lunar craters, including Ptolemaeus, Alphonsus, and Arzachel, in the highlands just east of Mare Nubium.

distance by a third star, a 9.1 magnitude red dwarf, designated **Castor C** or **YY Geminorum**.

The astonishing fact about this system is that each of these three "primary" stars is also a double! The Castor system is actually a six-star system with each member revolving around a common center of gravity. The true nature of this system remained a mystery until the invention of the spectroscope, and still stands as a remarkable example of a multiple star.

Moving 4.5° south-southeast, you'll encounter **Pollux**, or Beta (β) Geminorum — its name derived from the Greek word for "boxer." Pollux is the 17th brightest star in the heavens and is a stunning magnitude 1.2. As you have noticed, Castor is fainter, but designated Alpha, leading astronomers to believe that one of these stars has changed in luminosity in the last few centuries. Pollux is 35 light-years away and 35 times brighter than the Sun. It is a yellow "Arcturian" type star with a surface temperature of 4500 K. Don't confuse one star with the other. Many observers have spent hours trying to resolve the multiple nature of Pollux only to discover they were looking at the wrong star!





High in the sky at midnight this month lie M-81 (top) and M-82 — two galaxies in Ursa Major. For many people the very archetype of a galaxy, M-81 is a class Sb spiral. By contrast, the enigmatic M-82 puzzles astronomers with its irregular form. Roger Sliva used a 12½" f/5 scope and a 20-minute exposure on 103a-O.

"faint dim cloud of minute stars" with a total magnitude of 11. If this cluster were as close as M-35, it would surely rival the latter's prominence. Since it is so far away, it was relatively unknown and, until recently, rarely observed by backyard astronomers. An eight to ten-inch instrument at low power will probably pick up NGC-2158 just outside the field while you observe M-35. Take a look and see how it appears in your scope.

The stellar population in NGC-2158 suggests to researchers that it may be in an intermediate phase of evolution between a globular and an open cluster. Although astronomers don't know for sure if this is the case, NGC-2158 is another "addition to the short list of intermediate-age star clusters." The distance to this cluster is astounding — nearly 16,000 light-years — well beyond the range of normal open clusters.

Swing your scope back around to **Delta (δ) Geminorum**, and tap the tube 2° southeast of that double star. Now scan around in the nearby field and you should pick up **NGC-2392**, the **Eskimo Nebula**. The Eskimo is a small but bright planetary discovered by William Herschel, who described it as a 9th-magnitude star surrounded by an "atmosphere." A small scope will show it as an 8th-magnitude star embedded in a soft, hazy glow. In larger telescopes a "ghostly greenish blue color is evident." On nights of good seeing, you'll glimpse an outer ring separate from the brighter nucleus with a 10th-magnitude star sitting at dead center.

Burnham suggests several bright condensations lie in the inner nucleus and give the nebula the appearance of a face. The outer shell looks like the parka-type hood eskimos wear, hence the name. Burnham thought the nebula was the spitting image of W.C. Fields. The Eskimo is about 3000 light-years away, and its bluish-green color is produced by the "so called 'forbidden lines' of doubly ionized oxygen."

Before you pack up your equipment and trudge back indoors on this February evening, take a few minutes to scan randomly through the constellation. Since it lies so close to the Milky Way, Gemini is an excellent hunting ground for fainter targets not listed on sky atlases. Spend some time and discover your own clusters and asterisms much like Burnham, Webb, and Olcott did years ago.

In addition to holding some very fine stellar attractions, Gemini is home to many open clusters, maybe more than any other constellation. Open galactic clusters are some of the true showpieces of the sky. Although each is different, they all resemble grains of salt spilled on a dark blanket of black velvet. Tracking them down and comparing their beauty is one of the best ways to spend a February night.

Start out with the blockbuster **M-35**, the great open cluster lying at the foot of **Castor**. Olcott summed it up as "a marvelously striking object; no one can see it for the first time without an exclamation." M-35 measures 19' in diameter and is full of brilliant stars very similar in magnitude. "Nothing but the sight of the object itself can convey an adequate idea of its exquisite beauty," continues Olcott. An "elegant festoon" is easy to see near the center and the beauty of this cluster really stands out in small scopes at low power.

Burnham states that M-35 is visible in

opera glasses as a nebulous object and may be glimpsed in dark skies with the naked eye. Eta (η) Geminorum serves as a guide star since the cluster is only 2.5° away. M-35 is an excellent object for any size telescope and its beauty becomes particularly intense in a six to eight-inch instrument at low power. Burnham said that its "curving rows of bright stars give the impression of rows of glittering lamps on a chain — fainter stars form a sparkling background with an orange star near the center."

In a 24-inch reflector the cluster is a marvelously striking object — the field is full of brilliant stars equally distributed over the entire area. Harlow Shapley determined the field of view to be 46' and since 1930 a distance of 2700 light-years has been generally accepted.

Only half a degree southwest of M-35 lies the small compact cluster **NGC-2158**. It is very rich and much more distant than its larger neighbor and appears nebulous in a 6-inch.

William Olcott described it as a



Object	Type	Mag.	Size/Sep. Per.	R.A. (1950)	Dec.	R.A. (1982)	Dec.
NGC-2158	○	11.6	4'	06h04m	+24°06'	06h06m	+24°06'
M-35	○	5.3	19'	06h06m	+24°20'	06h08m	+24°20'
Eta (η)	★ ² ★	3.1-3.9, 8.8	233d, 1.4	06h12m	+22°31'	06h14m	+22°31'
20	★ ²	6.7, 6.9	20"	06h29m	+17°49'	06h31m	+17°48'
38	★ ²	4.7, 7.6	7"	06h52m	+13°15'	06h54m	+13°13'
Delta (δ)	★ ²	3.5, 8.1	6.3"	07h17m	+22°05'	07h19m	+22°01'
NGC-2392	■	8.6	47" x 43"	07h26m	+21°01'	07h28m	+20°57'
Castor (α)	★ ³	2.0, 2.8, 9.1	3"	07h31m	+32°00'	07h33m	+31°56'
NGC-2420	○	9.5	7'	07h35m	+21°41'	07h37m	+21°37'
Pollux (β)	★	1.2	—	07h42m	+28°09'	07h44m	+28°04'

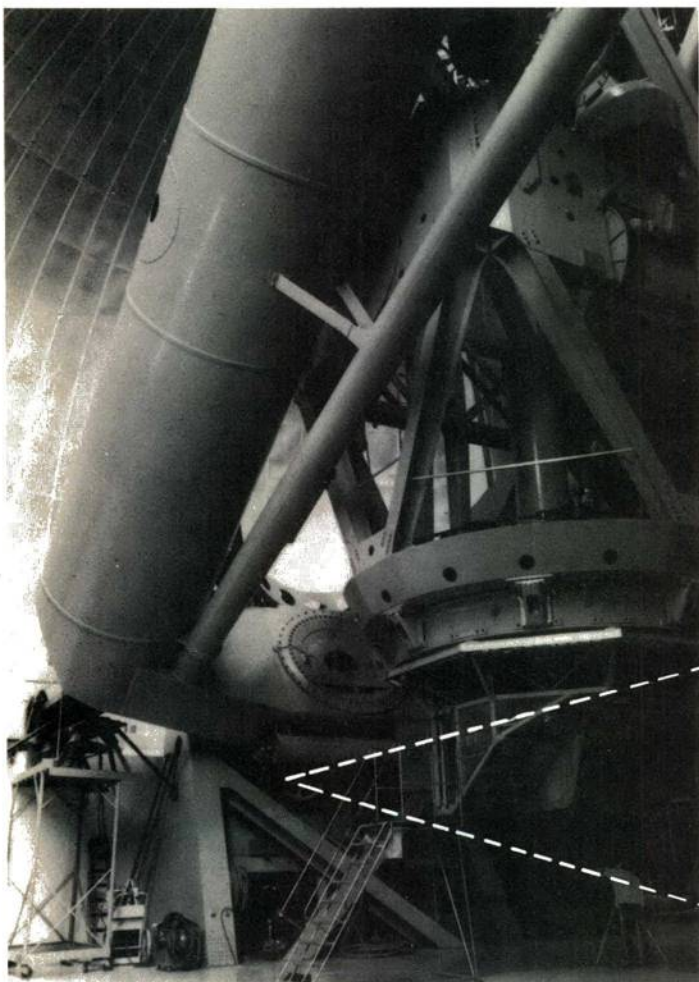
- ★ Star
- ★² Double Star
- ★³ Triple Star
- ★★ Regular Variable
- ★★ Irregular Variable
- ★★ Eclipsing Variable
- Open Cluster
- Globular Cluster
- Planetary Nebula
- Bright Diffuse Nebula
- §0 Elliptical Galaxy
- §S Spiral Galaxy
- §J Barred Spiral Galaxy
- §# Peculiar/Irregular Galaxy

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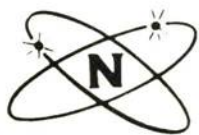
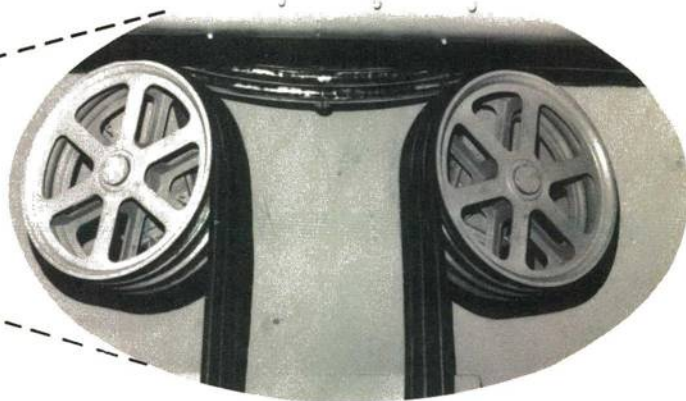
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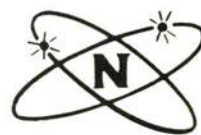
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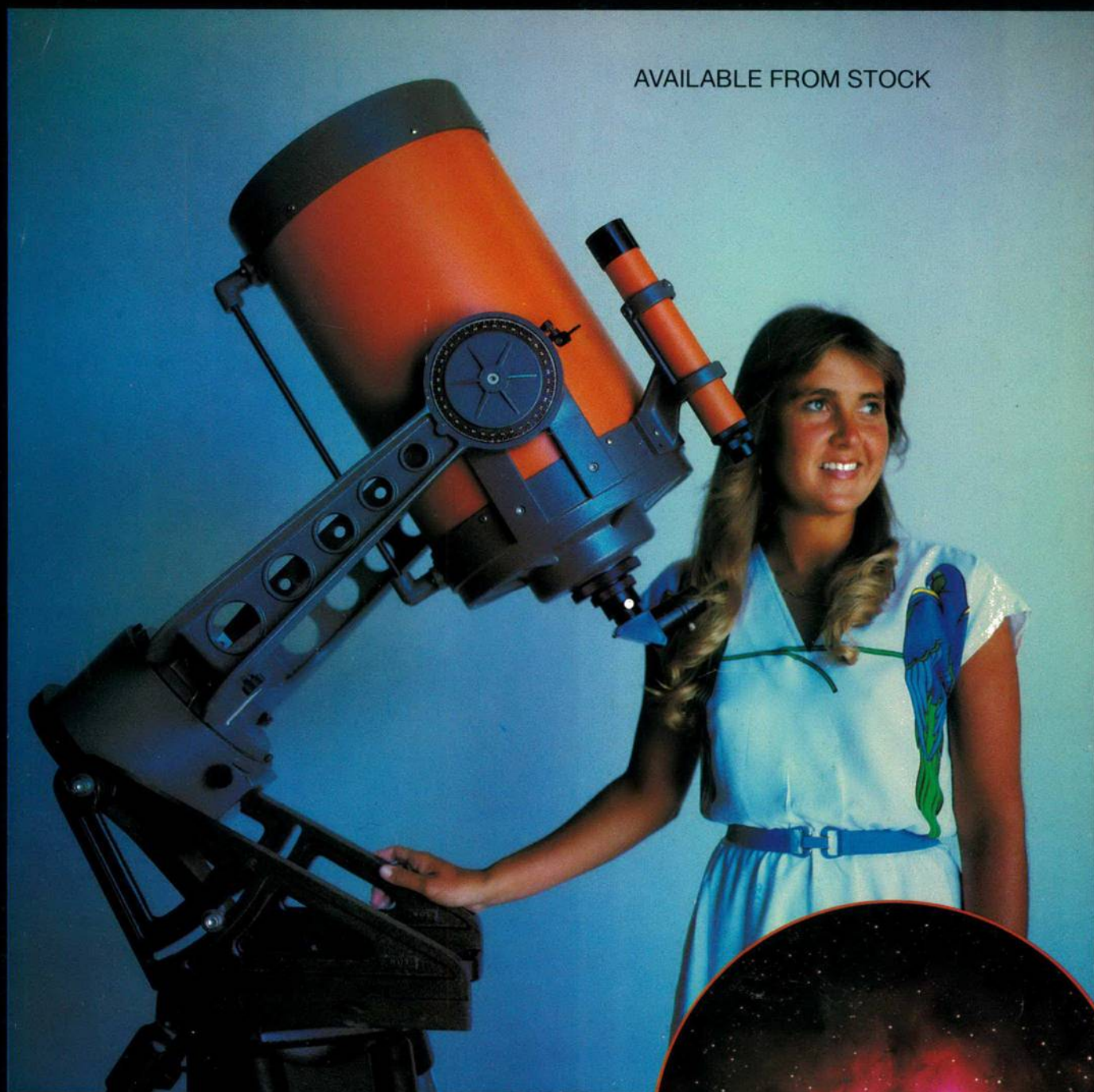
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